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RECOMMENDED PROCESSES AND BEST PRACTICES FOR NONDESTRUCTIVE INSPECTION (NDI) OF SAFETY-OF-FLIGHT STRUCTURES

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Materials Integrity Branch
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Interim Report

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14. ABSTRACT
This document outlines critical processes, guidelines, and best practices for the nondestructive inspection (NDI) of safety-of-flight aircraft (SOF) structures. More specifically, this document provides rationale for requiring rigor in the definition, development, demonstration and implementation of NDI for United States Air Force (USAF) SOF aircraft structures. Topics include the critical role of NDI in the Aircraft Structural Integrity Program, defining inspection requirements, procedure development, capability estimation, procedure qualification, training, certification, equipment controls and organizational structures. It is intended to be a "living" document to be updated, replaced or made obsolete by other documents at any time as the body of knowledge within the Air Force NDI community evolves. Although this document is intended as a compilation of best practices and recommended processes, it is not intended to state requirements or be referenced as for contractual purposes.
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14. ABSTRACT

The driving motivation is to improve the effectiveness of United States Air Force NDI operations. The catalyst for this document evolved in early 2004 with the discovery of several serious field and depot inspection escapes on multiple aircraft systems. A series of investigations concluded that the USAF NDI program had significant institutional deficiencies that required immediate attention. These activities culminated in the 2006 Air Force Nondestructive Inspection Summit in Dayton, Ohio that ultimately led to the formation of a working group devoted to compiling these lessons-learned.

The intended audiences are those stakeholders responsible for defining, developing, validating and implementing inspection processes to protect the safety of critical aircraft structures and structural components. Readers are expected to be familiar with the general concepts of nondestructive inspection, and have a general familiarity with the technologies involved, such as radiography, ultrasonic and eddy current inspection. Readers are not expected to have a background in NDI method application, technology development, structural design or statistical measures in NDI reliability assessments.

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1.0 Introduction

1.1 Purpose

This document sets out a series of recommendations designed to promote effective application of nondestructive inspection (NDI) on safety-of-flight aircraft (SOF) structures.

The driving motivation is to improve the effectiveness of United States Air Force (USAF) NDI operations. The catalyst for this document evolved in early 2004 with the discovery of several serious field and depot inspection escapes on multiple aircraft systems. A series of investigations, including the Eagle Look[1] and NDI Tiger Team[2] investigations, as well as related studies [3-7] concluded that the USAF NDI program had significant institutional deficiencies that required immediate attention. These activities culminated in the 2006 Air Force Nondestructive Inspection Summit in Dayton, Ohio that ultimately led to the formation of a working group devoted to compiling these lessons learned.

Each recommended practice and guideline is discussed in context and brief explanatory notes are provided. The recommendations are offered to all stakeholders and are intended as the basis for assessing conformance to the intent of Air Force (AF) directives, practices and procedures. Furthermore, within each section specific *Best Practices* are also defined. These *Best Practices* were identified as optimum practices implemented by the USAF, U.S. Navy or commercial airlines.

1.2 Audience

Readers of this document are expected to be familiar with the use of NDI as a means of ensuring the integrity of aircraft structures, and have a general familiarity with the NDI technologies involved, such as radiography, ultrasonic, and eddy current inspection. Readers are not expected to have a background in NDI method application, technology development, structural design, or statistical measures in NDI reliability assessments.

The intention is to make it clear to all involved the process and best practices for implementing effective inspections for SOF aircraft structures and establish a common basis of understanding. As a result of wishing to be clear to those not already involved in NDI, some of the statements within this document may appear to be obvious or trivial to those with experience in this area.

2.0 Stakeholders in the NDI Process

Stakeholders in the NDI Process include the following:

NDI Engineers and Inspectors - NDI procedure, technique and technology developers together with inspectors and other users of NDI processes who rely on integrity of inspection results and the information it provides to assist aircraft maintainers in their decision making.

Production and Maintenance Personnel - Those who rely on the integrity of the NDI processes and the information it provides to maintain the integrity and air worthiness of operational aircraft structures.

Group Managers and Trainers - Those who manage and train personnel in the detailed application of NDI methods, techniques and procedures.

Structural Engineers - Those who define structural design, usage and maintenance requirements and who are ultimately responsible for generation and definition of inspection requirements.

Aircraft Structural Integrity Program Managers - Those who are responsible for translating the requirements of MIL-STD-1530 and Air Force Instruction (AFI) 63-1001 into a program to manage the structural safety of an aircraft system.

3.0 Aircraft Structural Integrity Program, ASIP

Overview

SOF structure is defined as structure whose failure could cause loss of the aircraft or aircrew, or cause inadvertent store release. The loss could occur either immediately upon failure or subsequently if the failure remained undetected. To mitigate failure of such structures, the USAF has implemented the ASIP. This program defines a systematic process for establishing and maintaining managing the structural safety of Air Force aircraft.

The Office of the Secretary of the Air Force and HQ USAF make policy, advocate resources, and oversee ASIPs throughout the Air Force. Air Force Policy Directive 63-10 describes the specific authorities and responsibilities for ASIP. These are further detailed in AFI 63-1001. MIL-STD-1530C, *Aircraft Structural Integrity Program Requirements*, provides detailed direction on establishing and executing a tailored aircraft-specific ASIP and is required to be incorporated into all aircraft weapon system programs.

The objectives of the ASIP are to:

1. Define the structural integrity requirements associated with meeting Operational Safety, Suitability and Effectiveness requirements

2. Establish, evaluate, substantiate, and certify the structural integrity of aircraft structures

3. Acquire, evaluate and apply usage and maintenance data to ensure the continued structural integrity of operational aircraft

4. Provide quantitative information for decisions on force structure planning, inspection, modification priorities, risk management, expected life cycle costs and related operational and support issues

5. Provide a basis to improve structural criteria and methods of design, evaluation, and substantiation for future aircraft systems and modifications.

The Air Force instituted ASIP as the result of in-flight structural failures leading to catastrophic loss of B-47 aircraft in 1958; ASIP has been updated several times in the intervening years to further drive down the risk of Class A mishaps due to structural failures. The last major update was completed in 1975, incorporating the principles of damage tolerance.

Reviews are performed on every aircraft-specific ASIP every 1 to 2 years. In addition, the Air Force uses an annual conference sponsored jointly by Aeronautical Systems Center (ASC/EN) and the Air Force Research Laboratory (AFRL/RBS and AFRL/RXS),

to identify and promulgate ASIP process improvements. Feedback from all participants using ASIP is a keystone to implementing it most efficiently and to identifying necessary improvements.

The ASIP process establishes an approach for selection of aircraft structural critical parts/processes and the controls for these critical parts/processes. Figure 1 defines the logical path for classifying structural criticality within five primary categories:

- Fracture Critical Traceable - A SOF structural component that is either single load path or sized by durability or damage tolerance requirements.

- Fracture Critical - A SOF structural component that is not single load path nor sized by durability or damage tolerance requirements but requires special emphasis due to the criticality of the component.

- Mission Critical - A structural component in which damage or failure could result in the inability to meet critical mission requirements or could result in a significant increase in vulnerability.

- Maintenance Critical - A structural component whose failure will not cause a safety-of flight condition but is sized by durability requirements and would not be economical to repair or replace.

- Normal Controls - A structural component whose failure will not cause a SOF condition, is not sized by durability requirements and would be economical to repair or replace.

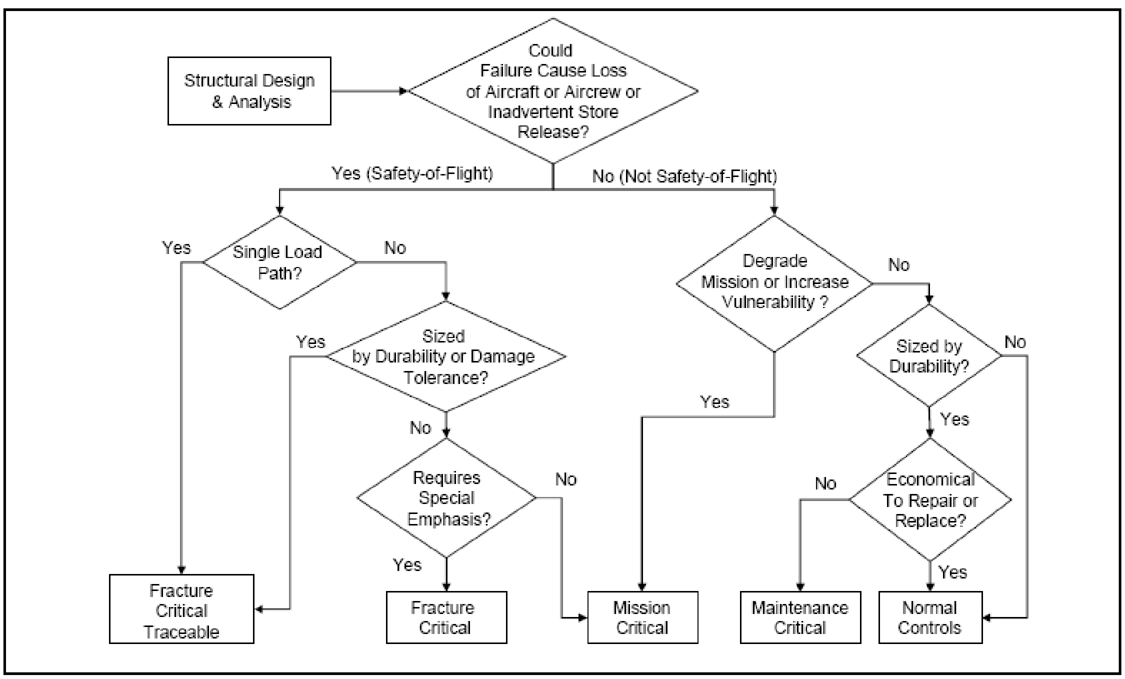

Figure 1. ASIP Process for Structural Classification (from MIL-HDBK-1530)

3.1 ASIP Tasks

The ASIP Program consists of five tasks.

Task I (Design Information)
Task I is development of those criteria which must be applied during design to ensure the overall program goals will be met. The expected usage, mission profiles, structural environments, and any other significant structural requirements are defined in this task. The ASIP Master Plan is initially drafted in Task I. The Air Force maintains this document through annual updates until the aircraft is retired. If there is a Dem/Val phase, then typically the AF requires that an ASIP Master Plan be developed in that phase. This document is helpful in establishing the System Development and Demonstration (SDD) requirements.

Task II (Design Analysis and Development Testing)
Task II includes the characterization of the environment in which the aircraft must operate, the initial testing of materials, components, and assemblies, and the structural analysis of the aircraft design.

Task III (Full-Scale Testing)
Task III consists of flight and laboratory (ground) tests of the aircraft structure to assist in determining the structural adequacy of the analysis and design. Major ground tests typically include full scale fatigue testing.

Task IV (Certification and Force Management Development)
Task IV consists of the analysis that leads to certification of the aircraft structure as well as the development of the processes and procedures that will be used to manage force operations (inspections, maintenance, modifications, damage assessments, risk analysis, etc.). The final analyses are performed in this task to include integration of the Task II and Task III results, culminating in the development of usage tracking programs, the Strength Summary and Operating Restrictions (SSOR), and the Force Structural Maintenance Plan (FSMP). It is within the FSMP document where structural inspection requirements are defined. These initial requirements are derived from the certification analysis conducted during Task IV.

Major activities within these Tasks I to IV are related to major program development milestones and thus provide visibility to management on the pace and success of the structural development program. The Air Force designed the program to reduce the risk progressively from Task I through Task IV. At the successful completion of Task IV, the risk of aircraft loss due to structural failure is low.

Task V (Force Management Execution)
Task V executes the processes and procedures developed under Task IV to ensure structural integrity throughout the life of each individual aircraft. This task may involve revisiting elements of earlier tasks, particularly if the service life requirement is extended or if the aircraft is modified. This task is mainly for the purpose of gathering structural

information (operational usage data, crack/corrosion findings, and tracking repairs), interpreting the impact of changes on the maintenance plan, and then implementing necessary changes to the maintenance program to ensure structural integrity through the service life. Task V is the responsibility of the AF; however, the AF may elect to contract some or all of this effort.

3.2 Force Structural Maintenance Plan – Defining Inspection Intervals

The intent of the design process is to achieve robust structures that require little, if any, maintenance within the design service life airframe assuming the system is flown within the anticipated loads and environmental spectrum. However, full-scale testing described in Task III and the certification analyses performed as part of Task IV may identify areas missed during design that require additional analysis, in-service inspections or perhaps implementation of production or in-service modifications. The FSMP defines when, where, how, and the estimated costs of these inspections and modifications.

In other words, the FSMP is the governing document which establishes the structural inspection, repair and modification requirements through the lifespan of each airframe. Furthermore, it is a living document that must be modified as airframe usage data, individual aircraft tracking data, analysis and inspection findings indicate changes are warranted.

Each inspection requirement is generally listed within the FSMP by an individual tracking number. Each requirement is further documented with the associated inspection method, initial and reoccurring inspection intervals and assumed inspection capability. SOF critical inspections should also be clearly defined within the FSMP.

It is the responsibility of the ASIP manager and the program NDI Level III to review and validate these requirements. Validation includes ensuring that the appropriate inspection methodologies are correctly applied and the assumed inspection capability is achievable.

Damage tolerance is the prevailing method employed by the USAF to manage repair, modification and inspection of fracture critical aircraft structures. Damage tolerance is the ability of a structure to retain its required residual strength for a period of unrepaired usage after the structure has sustained specific levels of fatigue, corrosion, accidental, and/or discrete source damage. Within the ASIP process, damage tolerance requirements are applied to all SOF structures classified as fracture critical and fracture critical traceable.

In simple terms, maintenance and inspection actions are scheduled such that damage does not grow beyond the size that possess an unacceptable risk to structural safety or grows beyond economical repair. Based on this approach, the initial inspection is required at time $\mathbf{T_i}$ which is defined as half the time an initial flaw of size, $\boldsymbol{a_o}$, (sometimes denoted as

a_i) needs to grow to the critical flaw size, a_{CRIT} (see Figure 2). The critical flaw size, a_{CRIT}, is the flaw size at which immediate and catastrophic failure of a structure can occur if the structure experiences design limit load.

The standard damage tolerance flaw size assumption for a_o is a 0.05-inch corner crack or a 0.100-inch surface crack. This is often termed the rogue flaw size.

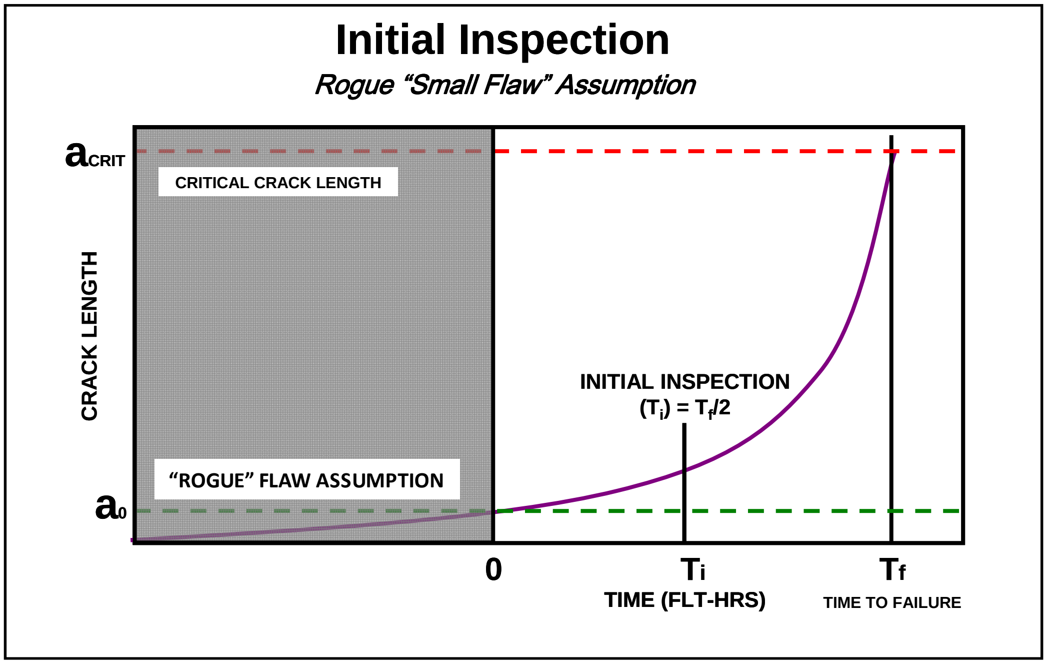

Figure 2. Defining the Initial Inspection

Recurring inspection intervals are established at half the time required for a crack to grow from the largest crack length that may be assumed to be missed during an inspection, a_{NDI} (sometimes denoted as a_{ASIP}), to the critical size a_{CRIT} (see Figure 3). If no crack is found during an inspection, the crack size is analytically "reset" to a_{NDI} (i.e., the structure is assumed to have a crack of length a_{NDI} present) and the next inspection interval is calculated as before (at half the time required for a crack to grow from a_{NDI} to a_{CRIT}).

This approach provides two opportunities to detect a crack prior to failure provided:

1. The loads are well understood through the ASIP Loads/Environmental Spectra Survey (L/ESS)
2. The aircraft usage is tracked through the ASIP Individual Aircraft Tracking Program (IAT)
3. The material properties in terms of fatigue propagation are accurate and the inspection capability, a_{NDI}, is conservatively estimated.

If a_{NDI} is not appropriately captured and a flaw larger than a_{NDI} is missed, then it is possible that the structure could fail catastrophically before the next inspection comes due

(see Figure 4). Recommended ***a_{NDI}*** values for common inspection methods are provided in the ASC/EN Structures Bulletin, EN-SB-08-012. Deviation from these values must be supported by formal probability of detection (POD) experiments.

Most AF aircraft programs utilize an IAT program to obtain actual aircraft flight and usage data. From this data various parameters are gathered that can be used to determine the damage growth rates throughout the aircraft structure. This usage data is then used to adjust the maintenance intervals for individual aircraft (by tail number) to account for either underutilization (extended intervals) or overutilization (reducing intervals). IAT programs are considered critical for effective implementation of scheduled inspections for SOF structures.

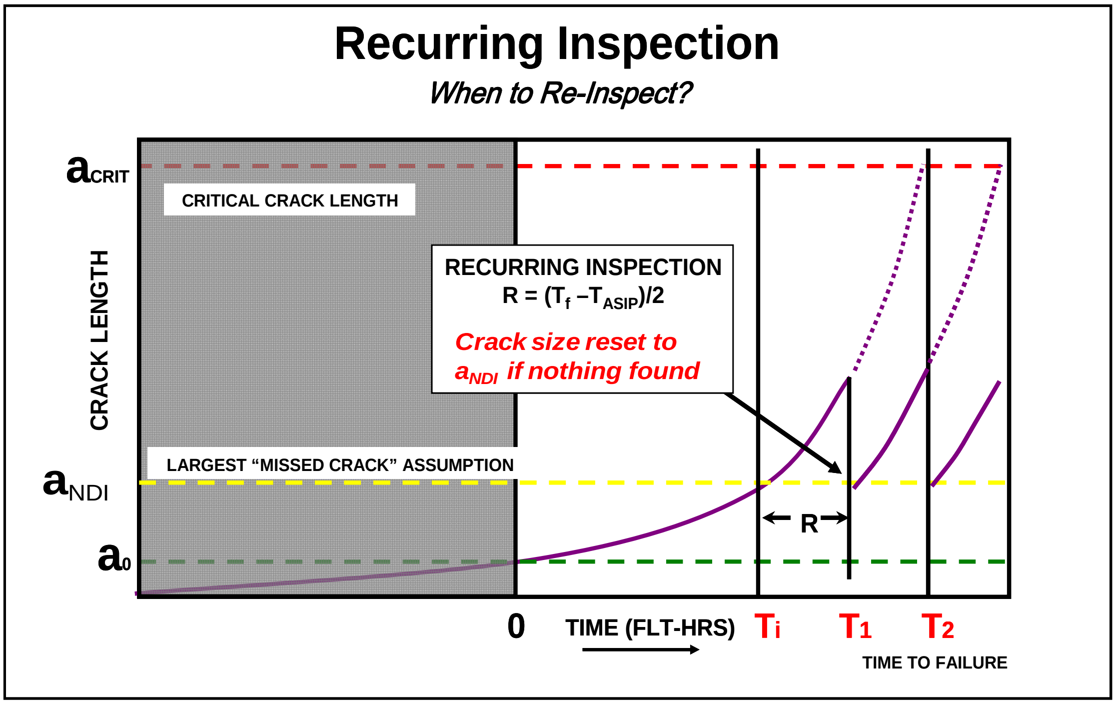

Figure 3. Defining the Recurring Inspection Interval

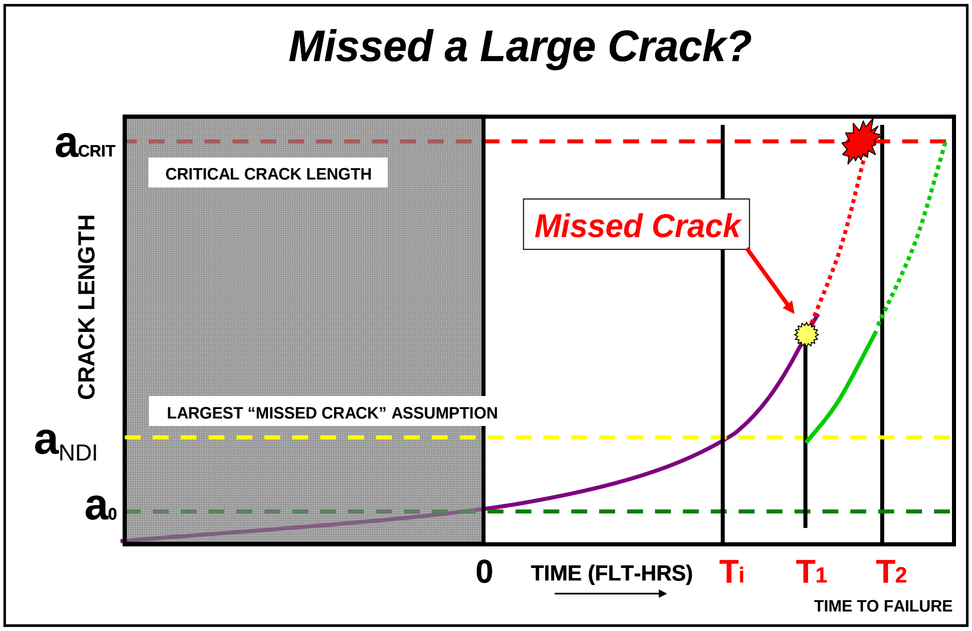

Figure 4. Possible Consequences of Missing a Flaw Larger than a_{NDI}

3.3 Risk of Managing Safety with Inspections

The probability of a crack miss (POM) is a function of the POD, probability of inspection (POI) and the crack size distribution in the aircraft structure. POD is a statistical measurement of the likelihood, of finding a flaw of a defined size using a specific inspection technique (see section 6.0). POI is the likelihood that an inspection is performed completely and accurately in accordance with technical data. As a result, the POM for a given crack size will increase with time as the crack population in the aircraft structure increases with usage if POD and POI remain constant.

The reliability of inspection processes is significantly influenced by inspector induced variability. As a result there is significant uncertainty within POD estimates used to establish the a_{NDI} of any given inspection method. Furthermore, it has generally been assumed that the POI for any given inspection is 100 percent while recent Air Force experience indicates POI values of 50 to 80 percent may be more typical. Because of these uncertainties the safety of SOF structures cannot be ensured through inspections alone.

The following scenarios attempt to illustrate various degrees of need for properly determining the a_{NDI} value considering the POD, POI and POM challenges. These scenarios attempt to balance both aircraft safety and cost/availability throughout the aircraft service life (See Figure 5).

<u>Scenario 1</u>: Aircraft are operated within the predicted damage tolerance life accounting for actual usage.

In this case, cracks are not likely to exist in SOF structure sized by damage tolerance requirements (e.g., assumed initial flaw size, a_0 = 0.05-inch). Furthermore, the Probability of Failure (POF) at the end of the damage tolerance life is most likely in the acceptable range because the POF is controlled by the probability of the assumed initial flaw size. In this scenario the $\boldsymbol{a_{NDI}}$ values are typically based on the 90 percent POD with a 95 percent confidence interval (i.e., $\boldsymbol{a_{NDI} = a_{90/95}}$). Increasing $\boldsymbol{a_{NDI}}$ values above the $\boldsymbol{a_{90/95}}$ value would result in excess maintenance.

<u>Scenario 2</u>: Aircraft are operated beyond the predicted damage tolerance life but less than the predicted durability life accounting for actual usage.

In this case, cracks are not likely to exist in SOF structure sized by damage tolerance requirements (e.g., 0.05-inch). However, the POF in this range of operation is probably higher than the acceptable range and must be controlled through inspections. For this scenario, selection of $\boldsymbol{a_{NDI}}$ should consider both POD and POI to establish the recurring inspection intervals.

<u>Scenario 3</u>: Aircraft are operated near or beyond the predicted durability life accounting for actual usage.

In this case, cracks may exist in SOF structure given the high probability of the assumed initial flaw size (0.005-inch to 0.01-inch range). The POF in this range of operation is higher than the acceptable range and must be controlled through inspections. For this scenario, selection of $\boldsymbol{a_{NDI}}$ must consider both POD and POI to establish the recurring inspection intervals.

<u>Scenario 4</u>: Cracks have been found in SOF structure.

A risk analysis should be performed to establish the recurring inspection intervals to control the risk to the acceptable level. The NDI POD function used in the risk analysis <u>must</u> include an estimate of the POI. If the POD and POI cannot be determined with a high degree of confidence, then the structure should be modified or the aircraft should be retired. In addition, a high degree of confidence should exist for the other key risk analysis parameters to include the flaw size distribution (reference Figure 6). This may require teardown inspection(s) of high-time/usage aircraft. The risk analysis should be used to establish the unmodified aircraft service life limit.

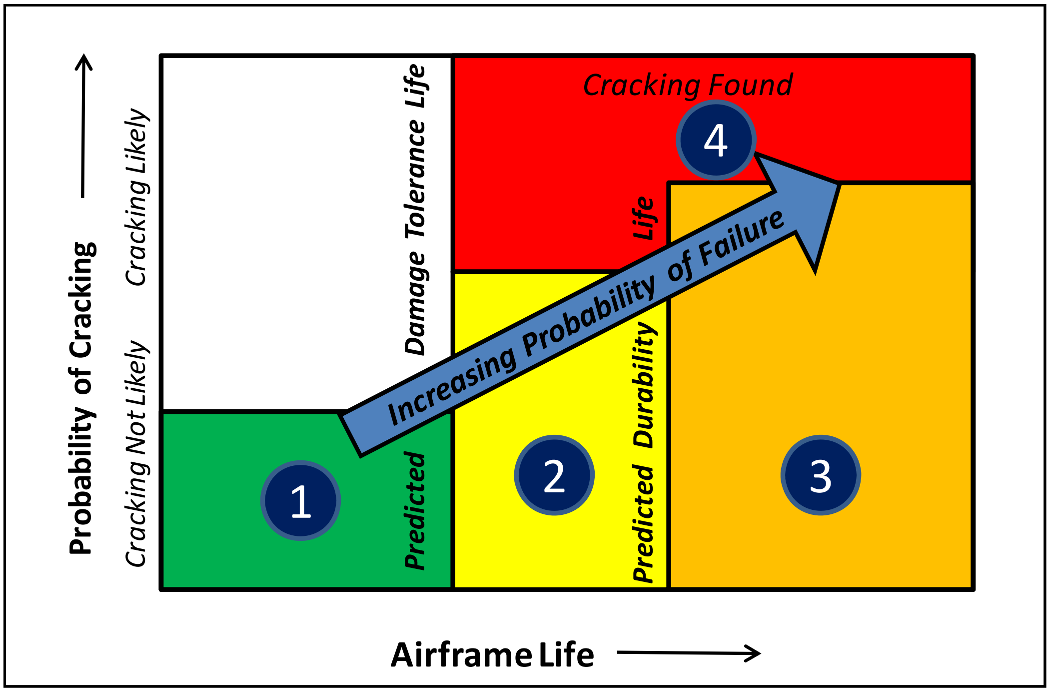

Figure 5. Scenarios for Increasing Probability of Failure with Increasing Crack Propensity and Airframe Life

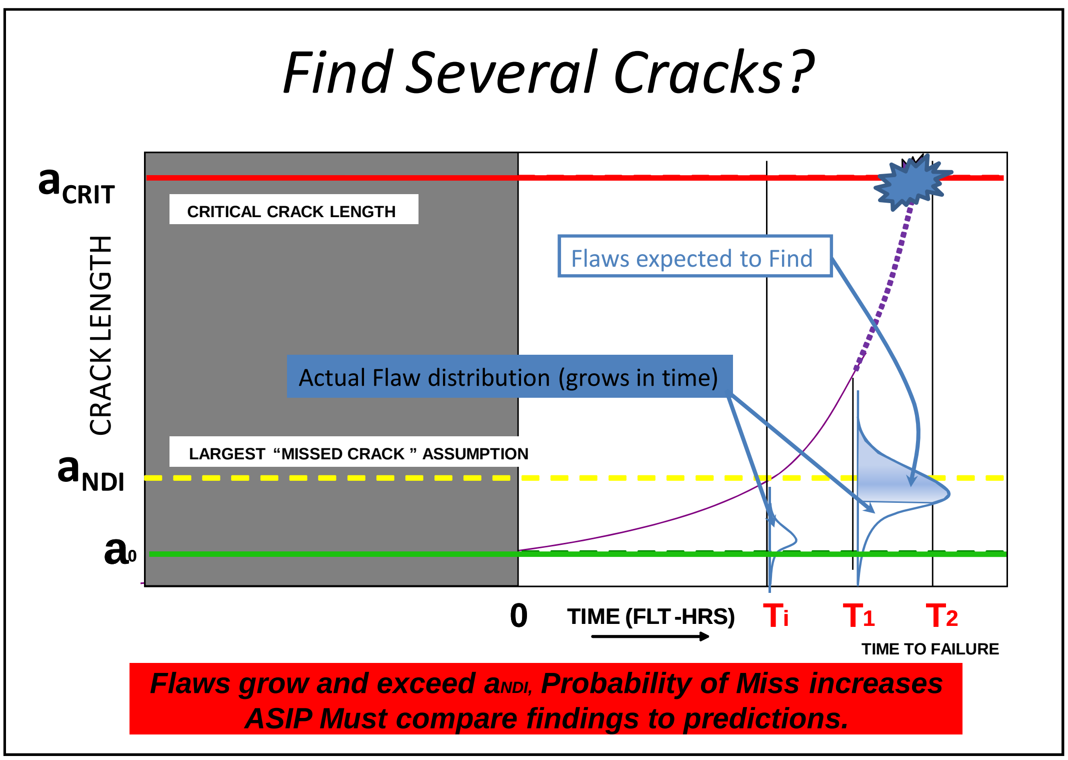

Figure 6. Comparing NDI Findings to Analytical Flaw Size Distribution Prediction

4.0 Defining Inspection Requirements

Inspection requirements are often stated in three conditions of detail:

Condition 1 - General Requirements: General inspection requirements typically captured within the FSMP and should be limited to basic assumptions and information. They should reference drawings and/or technical order (TO) instructions as they become available. This information is intended for engineers and Level III NDI personnel and is not intended to define inspection requirements to bench-level inspectors.

Condition 2 – Detailed Requirements Definition: Detailed requirements are often provided within a detailed requirement document or checklist and are intended as documentation of the inspection requirement from the structural engineer to the NDI Level III. The NDI Level III will be responsible for translating the requirement to an effective inspection process. Again, this is for engineers and Level III only. Again, this information is intended for engineers and Level III NDI personnel and is not intended to define inspection requirements to bench-level inspectors.

Condition 3 – Detailed Procedures: Detailed procedures are captured within technical order manuals or within Time Compliance Technical Orders (TCTOs). These procedures should contain all pertinent information and instructions necessary to perform the inspection and control its integrity.

Implementation of effective structural inspection solutions begins with clear and documented communication between the Structural Engineer responsible for generating structural maintenance requirements and the NDI Engineer (or NDI Level III) responsible for translating these requirements into practice. The communication and decisions that occur in the process of defining the inspection requirements must be clearly and formally documented. The following discussion provides guidance for developing the Detailed Requirements Definition (Condition 2) as described above.

BEST PRACTICE

Formally document inspection requirements in an Inspection Requirements Definition Document. This document (e.g., Memorandum of Understanding) should reflect the acceptance and understanding of the requirements definition through affirmation by signature from the responsible parties.

At a minimum, a detailed Inspection Requirements Definition must include the following elements:

Part Geometry

Part geometry definitions are often conveyed through engineering/production drawings usually developed and supplied by the system OEM. Often these drawings will define specific dimensional detail on an individual part or assembly basis but often will not adequately communicate all pertinent aspects of the required geometry definition, particularly for complex geometries or assemblies.

The level of detail required will depend largely on the inspection method required to inspect the component. Application of ultrasonic inspection, low frequency eddy-current and x-ray inspection will require a complete description of part geometric volume including location of attached members, location and type of fasteners in the inspection zone and details of any potential faying surface sealants or adhesives applied at interfaces. Application of surface eddy-current inspection, on the other hand, will be primarily dependent on the local surface geometry.

Part Material

The material description must include, in the case of metallic structure, the alloy type heat-treat or temper condition and a description of any surface treatments including coating or plating types and thicknesses. Material details are also required for all attaching members in the vicinity of the inspection zone. If fasteners are located within the inspection zone, the fastener type, including material composition (steel, titanium, etc.) must also be provided.

For composite materials, a fiber and resin description including number of plies and fiber stack-up directions is required. A complete material description of all attaching members is also required, including details of faying sealant or adhesives.

Flaw Location and Orientation

A clear and accurate definition of both the expected flaw location and orientation is required. These details will focus the inspection development, the resulting inspection procedure and ultimately the inspector's attention therefore, providing the optimum opportunity to maximize detection capability.

Access

A complete definition of the point of access as well as any potential access challenges must also be provided. This definition should include a description of a) panels or doors that must be removed to locate the component b) description of local structure or subsystems that may hinder access and c) an assessment of whether the inspection is within the inspector's direct line-of-sight or whether aids such as mirrors or borescopes are required. It is considered good practice to include detailed photographic documentation of the access with the requirements definition record.

Detectable Flaw Size

As described previously, Aircraft Structural Integrity Programs establish recurring inspection intervals based on the flaw size $\boldsymbol{a_{NDI}}$. When communicating inspection requirements to the program NDI Level III, it is good practice to provide both a ***goal*** $\boldsymbol{a_{NDI}}$ value and a ***threshold*** $\boldsymbol{a_{NDI}}$ value. The ***goal*** value is the inspection capability that may be very challenging to meet but would result in inspection intervals that would minimize the economic or maintenance burden to the program. The ***threshold*** value would be the inspection capability which cannot be exceeded. Larger values would result in an unacceptable economic or availability burden that could not be sustained by the program. For example, the inability to achieve the threshold size would require system groundings

or drive structural replacement or modification actions. In either case, both the goal and threshold values must be sufficiently smaller than the critical flaw size $\boldsymbol{a_{CRIT}}$ for that location such that the probability is very low that a flaw missed during the first inspection will grow to the critical flaw size before the next inspection opportunity. Recommended $\boldsymbol{a_{NDI}}$ values for common inspection methods are provided in the ASC/EN Structures Bulletin, EN-SB-08-012.

Flaw Nearest Neighbor(s)

A flaw's nearest neighbor is defined as any local geometry or detail that could result in a confounding response that could be misinterpreted as a defect or could mask a defect. Examples could include hidden fasteners or welds in metallic structures or even sudden ply drop-offs in composite laminates

Affectivity

A list of the affected aircraft or systems by serial number or tail number is also required. This information should include a description of any deviations or configuration changes in component design, including variances in any of the items described above. Such an accounting provides a level of assurance that all affected systems are inspected and that inspection processes are appropriately adjusted to compensate for known variances.

Configuration Changes

Any design changes as well as any known variances which may have resulted in deviations from blueprint during production should be documented. Records of production deviations may include any documented nonconformance as accepted by Materials Review Boards. In addition, standard repair processes that may have been applied to fielded components that may be encountered during inspection, should also be documented.

5.0 Requirements for Inspection Procedure Development

5.1 Considerations

When inspection requirements are translated into inspection processes, the resulting inspection solution must possess the following qualities:

Capable
The resulting inspection process must be capable of providing the required flaw detection capability needed to ensure structural integrity and ultimately system safety. Guidance for estimating inspection capability is provided in Section 6.0.

Reproducible
The inspection process must be sufficiently robust that the required performance, in terms of inspection capability, can be achieved by all inspectors independent of location and experience. This factor is largely a function of clearly written and technically complete inspection procedures and ensuring sufficient control of equipment and reference standard induced variability. Depending on the criticality and complexity of the inspection requirement, additional personnel and equipment controls may be required to achieve satisfactory reproducibility. These controls may include but are not limited to references standard master gauging, reoccurring equipment performance certification and inspector reoccurring task certification. It is the responsibility of the program Level III to define these requirements to achieve the required performance goals.

Repeatable
An inspection process must also provide repeatable performance from one inspection to the next. Repeatability is largely a function of monitoring and controlling the process to detect and prevent changes which could affect the overall detection capability.

For standard inspection methods used by the USAF, the required process controls are defined in TO 33B-1-2 as well as several industry specifications such as ASTM-E-1417 for penetrant inspection, ASTM-E-1444 for magnetic particle inspection.
Examples of such process controls include:

- Daily monitoring the performance of penetrant inspection lines using known crack specimens or cracked chrome panels.
- Using ketos rings to ensure a magnetic particle inspection bench and magnetic particle suspension are providing acceptable performance.
- Measuring film density after and exposure to ensure a proper exposure was accomplished.

BEST PRACTICE

When implementing new inspection process or technologies, the need for establishing new process control requirements must be considered. If process control measures are required, the control procedures and any associated process control devices must be implemented prior to full transition of the inspection process.

Sensitive to Relevant Variances/Insensitive to Non-Relevant Variances

When developing and implementing inspection processes, the NDI practitioner is always faced with maximizing signal-to-noise, i.e., maximizing detection sensitivity to relevant discontinuities while minimizing responses from non-relevant material or geometry variances. To successfully accomplish this, an understanding of flaw-to-flaw response variance must be obtained. Flaw response variation may result from crack closure differences due to residual stresses, crack angle variance, etc.

Furthermore, the potential response or ***noise*** from nonrelevant geometry and material variances must also be understood and minimized. Nonrelevant responses may include grain or surface coating induced noise, reflections or responses from internal or local geometry changes, etc.

Supportable

Successful implementation of inspection processes requires that supportability considerations be addressed. Inspection equipment must be sufficiently robust to preclude premature equipment failure particularly when exposed to the rigors of deployment. When failures occur, sufficient spares must be available or a process for rapidly repairing the assets must be in place. When delivering new inspections to the field a sufficient number of inspection kits and/or instruments must be provided to support both home base and deployment inspection requirements.

Trainable

Training requirements must always be considered when implementing new inspection processes. Depending on the complexity, criticality or unique nature of an inspection, specific training may or may not be required to successfully implement an inspection. In general, if an inspection process utilizes standard inspection equipment, standardized inspection processes, does not involve inspection of highly complex and is focused on specific structural details, then additional training may not be required. However, if the inspection utilizes new or unique equipment, complex procedures, or inspection of very complex geometries or numerous details then additional training may be required. It is the responsibility of the program Level III to identify, establish and implement training requirements prior inspection implementation. Further guidance for establishing training requirements and implementing training and certification programs is provided in Section 9.0.

Affordable

The affordability of an inspection process in terms of equipment, supplies, training and aircraft preparation manpower must be factored into the inspection process selection. The economic benefit of inspection options must always be weighed against other

potential options such as structural modification or replacement. It is always a best practice to evaluate the capability of existing equipment and processes prior to exploring more advanced, costlier options that could result in significant capital investment, training or long-term logistics costs.

5.2 Requirements for Procedure Development

5.2.1 Required Procedural Elements

Clearly written and technically accurate inspection procedures are critical for translating the inspection intent into practice. MIL-DTL-87929C, Technical Manuals - Operation & Maintenance provides specific requirements for the development of operation and maintenance technical manuals. Method specific procedure requirements are listed in the method specific Procedure Qualification Checklists detailed in Appendices A through E.

BEST PRACTICE
The method specific procedure qualification checklists provided in Appendices A-B should be references when developing new inspection procedures. These checklists outline the method specific recommended procedure content as well as a systematic process for validating inspection procedures.

The following discussion provides additional guidance and descriptions of critical elements of inspection procedures. All inspection procedures should include the following critical elements:

Affectivity
Procedures must include a list of affected aircraft tail-numbers or part serial numbers if applicable.

Safety-of-Flight (SOF)
Structural inspections that are have been defined as SOF by the systems Aircraft Structural Integrity Program Manager must be clearly identified as such within the body of the procedure (see NOTES and WARNINGS below). A list of safety-of-flight inspections should be listed within the system specific Force Structural Maintenance Plan as well as within the inspection technical manual (i.e. -36).

Structural Definition
Procedures should provide a complete description of the structural element to be inspected. The description should include the following as a minimum:

- Structural location
- Part number
- Materials
    Metals: alloy and condition (e.g., 7075-T6 Aluminum)
    Composite: fiber/resin system, number of plies, thickness (e.g., BMI graphite matrix, 16 plies).

Personnel Requirements
A definition of the inspector training and certification requirements must be provided.

For **military** personnel the following is required:
- AFSC Code: e.g. 2A7X2
- Certification Method (Fluorescent Penetrant, Eddy Current, etc.)
- Field Certification Level: (3-Level, 5-Level or 7-Level)
- Certification Standard (CFETP 2A7X2)
- Specific Task Certification Requirements (documented on a AF IMT form 1098 or AF IMT form 797 or AF IMT form 803).

For **civilian** personnel the following is required:
- Career Series: e.g. WG 3705
- Certification Method (Fluorescent Penetrant, Eddy Current, etc.)
- Certification Level (Level I, 2 or 3)
- Certification Standard AFMCI 21-108 (NAS 410)
- Method Specific Safety Training (Radiation Safety, etc)
- Specific Task Certification Requirements (Field - documented on a AF IMT form 1098 or AF IMT form 797 or AF IMT form 803, Depot – PACSS program).

Redundant Inspection Considerations
The requirement for redundant inspections must be considered. There are generally two types of redundant inspections:

Repeated/Independent Inspections: These constitute repeating the same inspection by a second, independent inspector without knowledge of the results of the first inspection. This approach will **not** improve the POD for the inspection technique but would reduce the risk that the inspection was not conducted properly or that the inspection area was not adequately covered, therefore improving the overall POI.

In accordance with the ASC/EN Structures Bulletin, EN-SB-08-010, the following three criteria shall be utilized to determine if a repeated/independent inspection of SOF structure is necessary. If any of the criteria are met, it is recommended that a second independent inspector perform the inspection to improve the POI and validate the no crack finding from the first inspection, and that the applicable Technical Orders be modified.

1. Evidence of a missed crack from any source (mishap investigation, recurring inspection, etc.).

2. Predicted percentage of locations expected to have cracking, based on durability testing and analysis which considers the inherent scatter in fatigue, is greater than the actual result.

3. Single flight probability of failure is expected to exceed $1x10^{-7}$ at any point at any time for any aircraft.

Second Method Inspection: This type of redundant inspection constitutes a second, independent inspection of the same inspection zone using a complimentary inspection method. Such an inspection could potentially improve both the POD and POI of the overall inspection. Example: Combining surface eddy-current inspection and focused fluorescent penetrant inspection.

Notes, Warnings, Cautions

Procedures must provide all pertinent Notes, Warnings and Cautions to 1) highlight additional nondirective critical information, 2) highlight critical procedural steps, and 3) heighten the inspector's awareness of safety-related procedural requirements.

BEST PRACTICE

Due to the criticality of inspections on safety-of-flight structures it is a best practice to highlight the importance of the task within the body of the procedure. This is best accomplished by placing WARNING at the very beginning of the part specific task. An example of such a warning is as follows:

WARNING

The following procedure constitutes an inspection of safety-of-flight components. Failure to perform this inspection completely and accurately could result in failure to detect critical flaws, resulting in the catastrophic failure of the structure, loss of the aircraft and serious injury or death to the pilot and crew.

Coatings, Plating

Procedures must provide a description of surface coatings or plating's that will be encountered during the inspection. Specific procedural guidance could include but may not be limited to the following:

- Compensating for inspection sensitivity debit resulting from the presence of coatings/plating
- Criteria for evaluating coating condition, thickness, and coating material makeup
- Preferred removal process for specific method or inspection
- Removal criteria

Surface Condition Requirements

Specific surface condition requirements including the following:

- Coating Condition (smoothness, integrity)
- Coating thickness
- Cleanliness
- Roughness.

If coatings are to be removed prior to inspection, the procedure must specifically state this requirement and required method of removal.

Access and Configuration Requirements
For on-aircraft inspections, procedures must clearly state the specific access and or aircraft configuration requirements. These requirements may include but are not limited to:

- Panels to be removed
- Tubing, wiring bundles, electronics, subsystems or structure removal requirements
- Jacking and leveling requirements
- Landing gear extension
- Etc.

Graphics (Visual Aids)
Detailed graphics must provide sufficient illustrative guidance to aid the inspector in 1) accurately locating the correct structure and detail and 2) interpreting the correct scanning, setup or calibration requirements.

Inspection graphics must include the following elements:

- Illustration of general aircraft structural location
- Illustration of access point
- Illustration of shop aid or probe guide to be used in inspection location.
- Detailed illustration of specific structural detail
- Inspection/Scan zone
- Scan plan or direction (i.e., eddy-current and ultrasonic scanning).
- Setup alignment details (i.e., film and tub-head placement for radiography)
- Ultrasonic beam direction in relation to transducer. (i.e., shear-wave direction).
- Expected flaw location and orientation
- Examples of appropriately calibrated signal responses (i.e., eddy-current and ultrasonic screen responses)
- Examples of both acceptable and rejectable indications (i.e., eddy-current and ultrasonic screen responses)
- Examples of possible noise responses as applicable.

Equipment/Inspection Aids
All equipment and inspection aids must be defined to include:

- Instrument/equipment type and model and part numbers
- Probe, transducer and cable model and part numbers
- Templates - Manufacturer part number or local manufacture
- Reference standard description and part number
- Image Quality Indicators (radiography)
- Tape
- Marking pencils
- Edge guides
- Illustration to be used in technical data.

Initial Equipment Set-up Parameters

Procedures should include instructions and tables defining the initial instrument set-up parameters. This provides a starting point from which critical parameters can be minimally adjusted to achieve the desired calibration response.

Calibration Requirements

Procedures must clearly define calibration (standardization) requirements. Details should include but not be limited to:

- Specific calibration target within reference standard
- Scanning requirements for locating reference target and maximizing reference response
- Acceptable calibration response
- Adjustments required to achieve required calibration level
- Recalibration requirements and intervals
- Recalibration failure criteria.

Inspection Procedural Details

Procedures must provide step-by-step instruction on the appropriate scan locations, scan plans and coverage, appropriate scan techniques that must be employed during inspection of the hardware. Such instructions should include but may not be limited to:

- Inspection coverage
- Scanning direction
- Scanning index
- Scanning speed
- Signal interpretation
- Inspector position and technique
- Exposure energies and times (radiography).

Evaluation Criteria

Procedures must provide guidance to the inspector to effectively evaluate and interpret the resulting inspection response. Evaluation criteria should include but not be limited to:

- Signal shape, amplitude and location
- Indication size, shape and spacing.

Acceptance Criteria (Threshold Levels) Quantified and Useful

Acceptance criteria must be quantifiable and clearly communicated. Acceptance criteria should be stated in terms of the response for the specific inspection modality. Furthermore the acceptance criteria must be established that will discriminate relevant response variances from non-relevant variances in order to reduce or eliminate the potential for false-positive indications.

Penetrant Example 1: For the case of fluorescent penetrant inspection for surface breaking cracks, it is not acceptable to establish the acceptance criteria as “No Cracks Allowed”. Alternately, more effective criteria could be “No Linear Indications

Allowed". Linear indications would further be defined as "Indications with length 3X the indication width".

Eddy Current Example 2: For the case of rotary bolt-hole eddy current inspection, quantifiable criteria could be based on a response threshold e.g., "All indications exhibiting a 40 percent Full Screen Height (vertical) response shall be rejectable".

Recording/Notification Requirements

Procedures must define the documentation, reporting and notification requirements to ensure that all inspection findings are appropriately archived and communicated to the responsible engineering authority. These requirements are method or procedure specific and should include but not be limited to the following:

- Inspector (Name, Certification Level)
- Date of Inspection
- Aircraft Tail Number (if applicable)
- Part Number
- Part Serial Number
- Technical Order or Procedure Reference
- Set-up/Process Details
- Required paperwork/documentation (e.g., Form 806, Form 39)
- Photographic documentation
- Indication/damage size
- Indication/damage orientation
- Instrument screen shot of defect
- Electronic database input
- Engineering authority notification requirements to include organization and Points of Contact.

Post Inspection Actions

Actions required after inspection completion must also be incorporated. Such actions could include the following:

- Cleaning requirements
- Application of coatings or corrosion protective compounds
- Return aircraft to original configuration.

6.0 Estimating Inspection Capability

6.1 Objective and Scope

The objective of this section is define and summarize the practical approaches and best practices for generating estimates of nondestructive inspection capability. *MIL-HDBK 1823, Nondestructive Evaluation System Reliability Assessment*, was established in the early 1990s to provide guidance for the design and execution of POD experiments. As such, it is considered the USAF BEST PRACTICE for conducting POD experiments.

Unfortunately, due to the high cost and time required to conduct extensive POD experiments, extensive MIL-HDBK-1823 experiments have rarely been accomplished for structural inspection requirements. Historically, inspection capability estimates have been based on solely on "engineering judgment" often resulting in very optimistic (i.e. unconservative) estimates.

The following discussion provides general guidance for conducting large scale MIL-HDBK-1823 type experiments, approaches for conducting limited capability experiments, and guidance for using existing data to estimate application specific capability. Statistical methods for calculating probability estimates are defined in detail within MIL-HDBK-1823 and, therefore, will not be repeated here. This discussion is not an exhaustive treatment of this subject but is intended only as a summary of the various approaches. This section will be expanded in future amendments of this document.

6.2 Background

Historically, four primary methods have been used or considered in the estimation of inspection capability or $\boldsymbol{a_{NDI}}$ for inspection systems: a) engineering judgment, b) theoretical modeling, c) past inspection results, and d) demonstration experiments. Use of engineering judgment or a comparison to past inspection results, without the benefit of rigorous empirical support, has been used to establish inspection capability for most AF safety-of-flight structures. This is **not** the preferred approach.

The most common method for quantifying the reliability and sensitivity of an NDT system is POD analysis. This method developed, by Berens [8], Spencer [9] and Rummel [10], estimates detection capability as a function of discontinuity size. The POD at a discontinuity of characteristic size "***a***" is defined to be the average probability of detection of all discontinuities at the size "***a***". This definition reflects the fact that the detectability of discontinuities will vary with a number of factors, including but not limited to size. Therefore the POD curve is drawn through the mean POD for each discontinuity size. Since there is statistical uncertainty in the parameter estimates, there is also statistical uncertainty in the estimate. To account for this uncertainty, a statistically based upper confidence limit can be applied to the estimate. Usually, a 95 percent confidence limit is used for this characterization of inspection capability (Figure 7). A

number of methods have been used in the past to establish the 95 percent confidence bounds, accepted statistical treatments are defined with MIL-HDBK-1823.

The point at which POD(a) = 0.90 is often referred to as the a_{90} value. The point at which the 95 percent confidence bound intersect the POD(a) = 0.90 point is commonly designated as the $a_{90/95}$ crack size for an inspection.

The $a_{90/95}$ value, commonly referred to as the a_{NDI} value, is typically used for establishing reoccurring inspection intervals. This value represents the flaw size that will be detectable 90 percent of the time with 95 percent confidence that the flaw size is at or below that value.

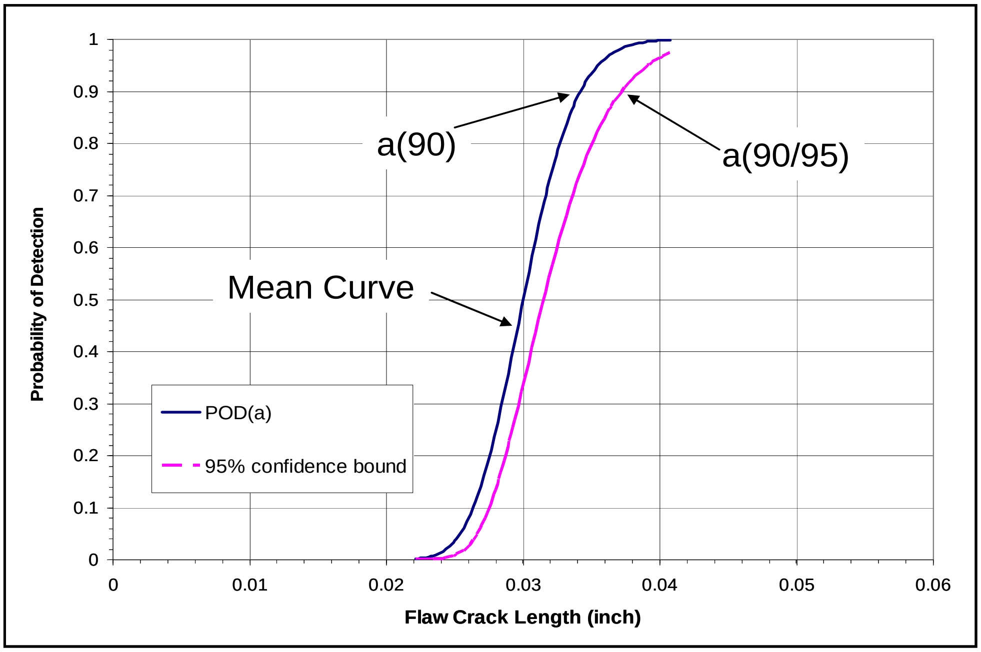

Figure 7. Typical POD Curve

The following sections provide an overview of the two most common approaches for establishing inspection capability using empirical data. Guidance for applying existing capability data to new inspection problems, to include uses of transfer functions, is also provided. Lastly, guidelines for conducting experiments using limited data sets are also discussed.

6.3 Factors Affecting Reliability

There are numerous factors that can affect the reliability of any NDT technique. Some are fixed or controlled, such as the frequency of excitation of the ET instrument, some are uncontrolled such as the fastener hole quality in a bolt hole inspection. Any experiment to estimate reliability should begin by listing the relevant factors or variables, and

determining which factors will be addressed and how. As a minimum, the following types of factors should be considered:

- Specimen Condition – Includes surface cleaning, abrasive blast, access restrictions and general surface condition.
- Inspector – Includes the number of inspectors, inspector qualifications, experience and physical ability.
- Sensor – Type of sensor, number of sensors to be tested and control of sensor variability.
- Inspection Setup and Calibration – Includes type of calibration standards and processes used to setup and calibration instrumentation to include procedure documentation.
- Inspection Process – Includes an assessment of the process variables including scan rates, scan path index, dwell times, etc. Extremes of the process variables should be included in the experimental design.

Table 1 provides an example of a categorization of factors with the potential to affect the reliability for eddy current inspection of aircraft structures for fatigue cracks. In any particular situation, some factors may be more or less important while others may have a significant effect on the overall result.

Table 1. A Partial List of Controllable and Uncontrollable Factors Influencing Bolt Hole Eddy Current Inspection

Controllable Factors	
instrument	define a fixed type for a technique
instrument frequency	define a fixed value for a technique
instrument gain	define a fixed value for a technique
instrument phase	define a fixed value for a technique
instrument filters	define a fixed value for a technique
probe	define a fixed type for a technique
Uncontrollable Factors	
instrument variance	variance between instruments of same type
probe variance	variance between probes of same type
inspector variance	variance between different inspectors
probe-part positioning variance	variance due to human/mechanical position errors
crack variance	variance between cracks of same nominal size: aspect ratio, nucleation feature, etc.
part geometry variance	variation in geometry of inspection locations may vary due to drawing tolerances and material process callouts, i.e., forging vs. castings
materials properties variance	variations in conductivity from batch to batch, variations in residual stress, random variations in grain size, inherent surface roughness, etc.

6.4 POD Estimation Methods (MIL-HDBK-1823)

The USAF typically uses two common types of statistics for the estimation of inspection capability or POD. The two categories are **Hit-Miss** analysis and curve-fitting, ***â*** versus ***a*** methods.

The Hit-Miss approach refers to an NDI system which gives results as either indicating the presence of a discontinuity (Hit) or the lack of a discontinuity (Miss) on the inspection subject. This methodology is best applied to inspections were a clear relationship between flaw size and flaw response may <u>not</u> exist or where quantifying the response may be difficult. Hit-Miss analysis is the typical approach when evaluating inspection techniques were the inspector provides a qualitative visual discrimination of the flaw response such as visual inspection, penetrant inspection, magnetic particle inspection or film radiography.

The ***â*** versus ***a*** approach refers to an NDI system where the results of the inspection are based on the quantified and recordable magnitude response or signal amplitude ***â***. The POD(*a*) function can be estimated from the statistical scatter in the response as a function of crack size, ***a***. This ***â*** versus ***a*** approach is applicable when a quantitative signal response can be correlated to flaw size as typically attainable with techniques such as ultrasonic or eddy-current inspection.

6.4.1 Hit-Miss Analysis

For many inspection techniques, such as fluorescent penetrant, magnetic particle and radiography the response achieved from a flaw often cannot be directly related to flaw size. Therefore, the inspection results produced from such inspection are typically represented by a Hit represented as a value of 1, and a Miss represented as a value of 0 (Figure 8).

Hit-Miss analysis, described in detail within MIL-HDBK-1823, is an estimation approached based on the log-odds model where the probability of detecting a flaw is calculated using a likelihood function to estimate the probability of whether a flaw size, ***a***, will produce a miss (0) or a hit (1). Because this estimate is based on a two-parameter (hit, miss) model, the flaw distribution used within the experiment is critical to obtain a valid estimate.

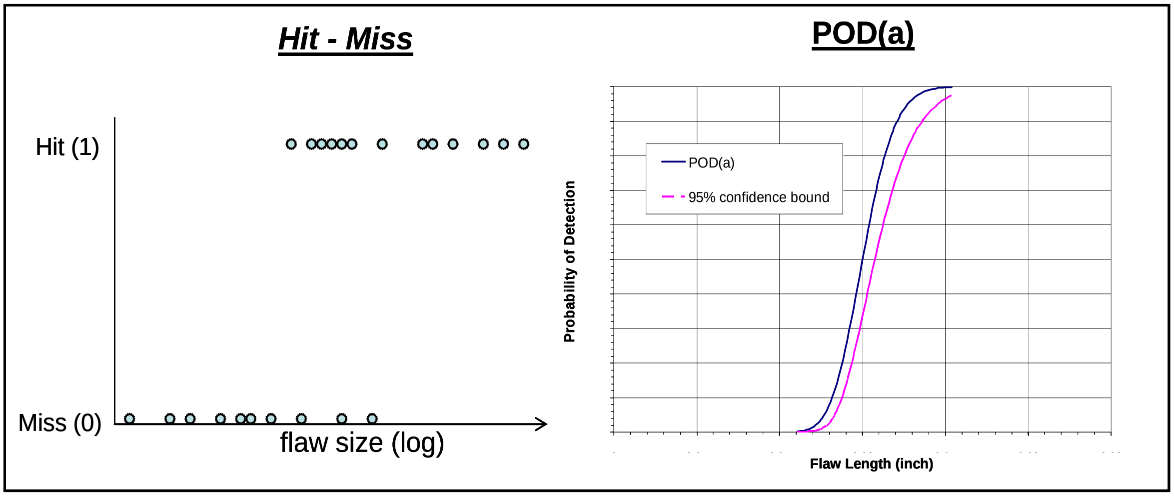

Figure 8. POD Hit-Miss Model

6.4.1.1 Guidelines for Conducting Hit-Miss Experiments

Number and Distribution of Flaws

To minimize the chances of completely missing the crack, to provide maximum information over a broad flaw size range, and to accommodate use of specimens for multiple applications, the sizes of flaws in a specimen set should be uniformly distributed between the minimum and maximum of the sizes of potential interest. Mil-HDBK-1823 [4] recommends that a minimum of 60 flaws should be distributed in this range, but as many as are affordable should be used.

Unflawed Inspection Sites

In the context of the preceding discussion, sample size refers to the number of known flaws in the specimens to be inspected during the capability demonstration. The complete specimen set should also contain inspection sites that do not contain any flaws. If the inspection results are of the hit-miss nature, at least twice as many unflawed sites as flawed sites are recommended. The unflawed sites are necessary to ensure that the NDE procedure is truly discriminating between flawed and unflawed sites and to provide an estimate of the false call rate. If the NDE system is based on a totally automated $\hat{a}$ versus a decision process, many fewer unflawed sites will be required. If any $\hat{a}$ values are recorded at the unflawed sites, their magnitude would provide an indication of the minimum thresholds that might be implemented in the application.

Number of Inspectors:

When conducting any POD experiment, a significant sampling of inspectors is required to obtain statistically significant estimates. It is recommended that at least 10-percent of the inspector population or at least 10 inspectors be included in the experimental design, whichever is larger. If inspections are expected to be conducted by fewer than 10

dedicated inspectors, then it is recommended that each inspector within that group participate in the experiment.

6.4.1.2 Example: Hit-Miss Analysis

An experiment was conducted to establish a capability estimate for a depot-based fluorescent penetrant inspection line. The penetrant line was a fourteen station (Method D) system using Level 4 penetrant (ultra-high sensitivity) penetrant and dry powder (form a) developer.

Specimen Set

Forty flat panel POD specimens were used. The specimens were 0.25 inch thick, 3 inches wide and 6 inches long. They were made of Inconel 718 and contained cracks ranging in size from 0.0039 to 0.2514 inch long. Of the 40 specimens, 20 contained a total of 89 cracks. The cracks were randomly located on the panels. Grid reference plates were provided that framed the perimeter of the specimen to assist the inspector in identifying the location of flaws on a map. One map sheet was provided for each specimen to document the cracks found. The map was compared to a key retained by the monitor observing the process. Misses and false calls were identified by the monitor upon completion of each panel inspection.

After each processing and inspection run, all panels were thoroughly cleaned.

Experimental Parameters

The specimens are placed in wire frame baskets and an operator shuttles the basket over rollers from station to station. Engineering controls were applied at each station (i.e., penetrant immersion, pre-rinse, emulsifier immersion, and developer fog chamber stations) to control application and exposure to the materials. Dwell and drain times and all process parameters were controlled by a detailed written procedure. Specific process parameters are summarized in Table 2.

Table 2. Fluorescent Penetrant Process Parameters

Process	Parameter
Penetrant Dwell	30 min
Pre-rinse time	120 sec
Emulsifier Dwell	2 min to 15 min
Rinse max psi/°F	20 psi/80 °F
Drying Temp °F	140 °F
Developer Dwell (form a)	15 min
Black Light Intensity	1700 to 2400 $\mu W/cm^2$ @ 15 inches
BL White Light	3.3 ft-c
Ambient Light	1.5 ft-c
Evaluation Developer Dwell	Varied up to few minutes

All five inspectors performing FPI within that facility conducted independent processing and inspection of the specimens at a rate of one inspector per day.

Analysis

The PODSS Version 3 software and Hit-Miss model, was used to generate both composite and individual inspector POD(a) estimates. Individual inspector $a_{90/95}$ values ranged from 0.044 to 0.059 inch, the composite $a_{90/95}$ value is 0.053 inch (Figure 9).

False positives (indications misinterpreted as cracks) for each inspector were 2, 3, 39, 16 and 9.

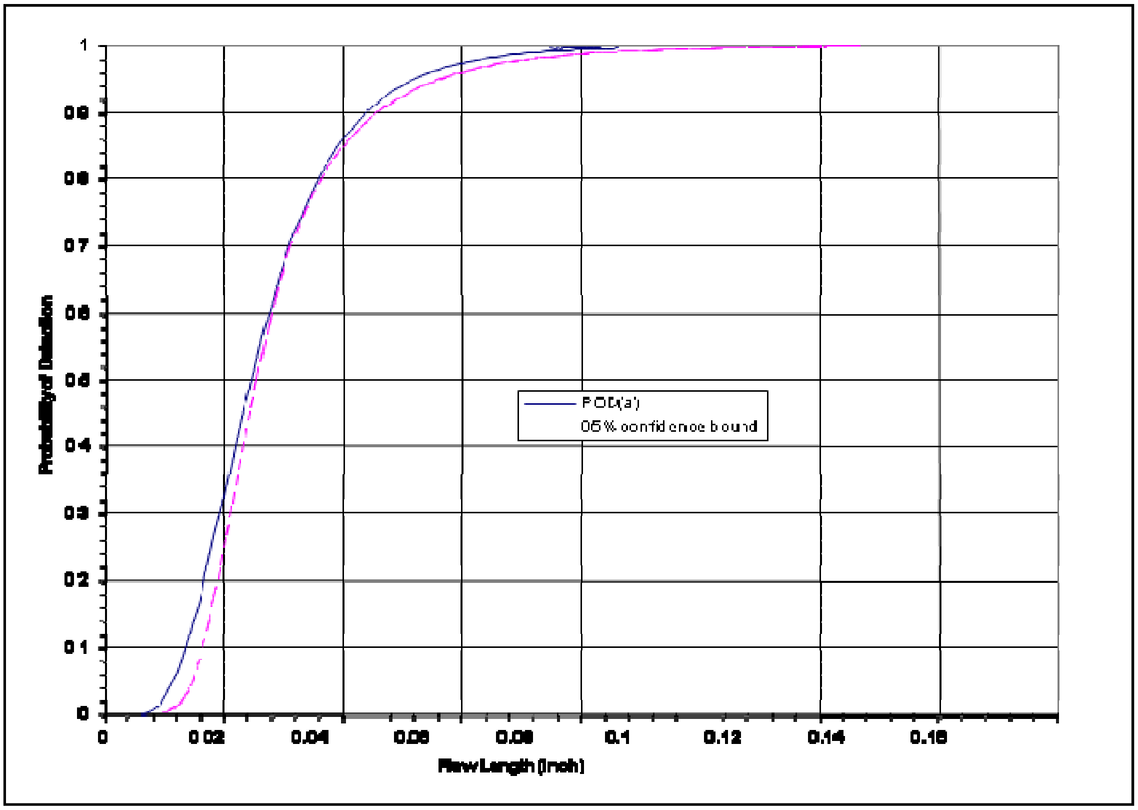

Figure 9. POD Composite Results, Hit-Miss Model

6.4.2 *â versus a* Analysis

For many inspection techniques, such as ultrasonics and eddy current, the response achieved from a flaw can often be related to the flaw size. For such inspection methodologies an ***â*** versus ***a*** approach can be used to estimate the probability of detecting a flaw of size ***a*** at a given rejectable signal threshold $\hat{a}_{th}$. This approach is very powerful in several ways:

1. It allows the reevaluation of the probability solution at any signal threshold level merely through an analysis of the original data.
2. It permits evaluation and selection of the appropriate threshold level to minimize false positives.
3. A shift in capability resulting from a change to the original inspection process can be estimated using the original ***â*** versus ***a*** data set provided the difference in the system can be isolated and measured.
4. The ***â*** versus ***a*** data from one inspection system can also be used to estimate of other inspection systems through the use of ***transfer functions*** without the need to repeat extensive experiments. This approach is applicable if an estimate of the differences between the two inspection systems can be isolated and measured.

For ***â*** versus ***a*** type data, it has been noted that in many cases the logarithms of ***â*** and ***a*** are linearly related. It is common practice to assume a log (***â***) vs. log (***a***) (see Figure 10) relationship for describing NDI data; however, other models may be applicable to depending on the inspection response. These models may also including Cartesian ***â*** vs. log (***a***), log (***â***) vs. Cartesian ***a.*** Proper selection of an appropriate model is critical for generating accurate POD results. Detailed guidance for selecting the model is provided in MIL-HDBK-1823.

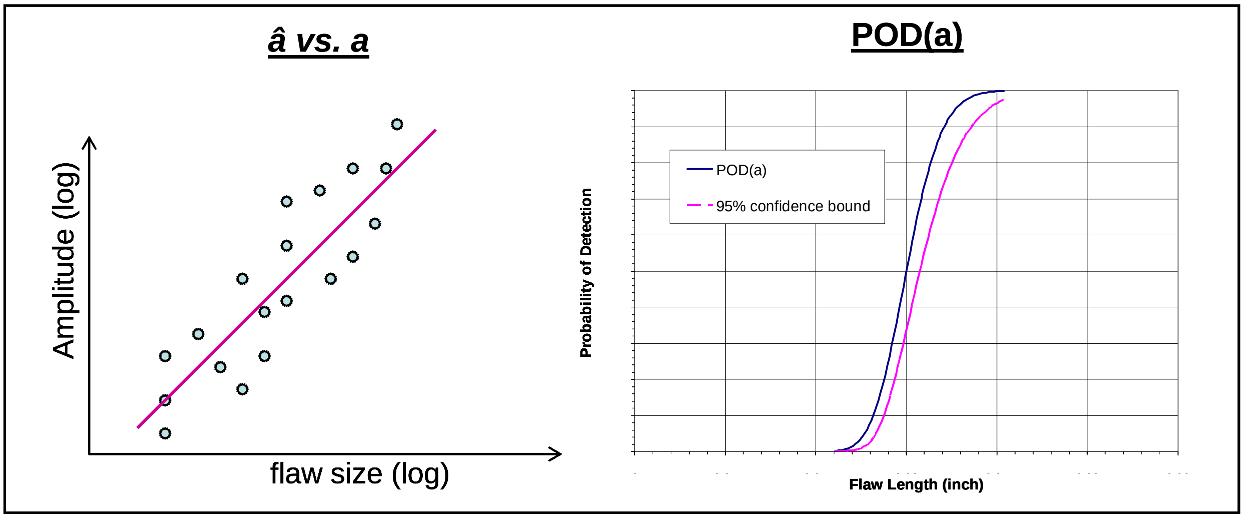

Figure 10. POD *â* versus *a* Model

6.4.2.1 Guidelines for Conducting *â* versus *a* Experiments

Number and Distribution of Flaws:
Because of the added information in the ***â*** data, a valid characterization of the POD(***a***) function with confidence bounds can be obtained with fewer flaws than are required for the hit/miss analysis. MIL-HDBK-1823 recommends at least 40 flaws within the demonstration specimen set. Increasing the number of flaws increases the precision of estimates, so the specimen test set should contain as many flawed sites as economically feasible. The analysis will provide parameter estimates for smaller sample sizes, but the adequacy of the asymptotic distributions of the estimates is not known. The flaw sizes should be **uniformly distributed** between the minimum and maximum of the sizes of potential interest.

Unflawed Inspection Sites
Again, it is recommended that twice as many unflawed sites as flawed sites are included in the demonstration specimen set; however, if the NDE system is based on a totally automated ***â*** versus ***a*** decision process; fewer unflawed sites may be required. If any ***â*** values are recorded at the unflawed sites (i.e., noise), their magnitude would provide an indication of the minimum thresholds that might be implemented in the application to reduce false positives.

Number of Inspectors:
It is recommended that at least 10 percent of the inspector population or at least 10 inspectors be included in the experimental design, whichever is larger. The inspection personnel should be randomly selected from the population. If inspections are expected to be conducted by a group smaller than ten individuals then it is recommended that each inspector within that group should participate in the experiment. If more than one shift is involved, the experimental population should be selected from the all shifts.

6.4.2.2 Example - *â* versus *a* Analysis

An experiment was conducted to establish a capability estimate for detection of corner fatigue cracks in aluminum fastener holes using rotary eddy current inspection. The TO 33B-1-2 procedure, *EDDY CURRENT, TITANIUM, ROTARY FASTENER HOLE*, was used. The procedure defined the specific eddy-current instrument, scanner, and probes to be used. Instrument set-up parameters were also specifically defined as well specific reference standard and reference notch size callouts.

Specimen Set
The demonstration specimen set consisted of 50 donut-shaped titanium (Ti-6-4) discs containing fatigue cracks within the 0.416 inch diameter bore. A total of 44 mid-bore fatigue cracks were populated within the specimens with no more than one crack per specimen. Crack lengths were 0.012 to 0.042 inch. Crack aspect ratios were reported to be 2:1 (length: depth). The specimens were fixture in an overhead position to simulate a typical overhead fastener hole inspection.

Experimental Parameters

After a brief training period (generally less than 30 minutes) each inspector completed inspections of all 50 specimens within the specimen set. The facilitator controlled the experiment by mounting each specimen overhead and by recording the inspector findings as they were reported. The maximized peak-to-peak amplitude and clock position was recorded for all indications that were distinguishable from the baseline noise (approximately 10 percent vertical peak-to-peak).

Probability of detection curves were calculated for individual inspectors and as a composite, using the *POD Version 3* software. An $\hat{a}$ (flaw response) versus a (flaw length) analysis was used. A log $\hat{a}$ - log a model was assumed. A 40 percent vertical signal rejection threshold was selected. The minimum and maximum signal values were selected, for each individual inspector data set, to optimize the test of assumptions (Normality, Equal Variance, and Lack of Fit).

Noise Estimates and Threshold Selection

On-aircraft baseline noise measurements were acquired using the same inspection equipment procedures. A maximum peak noise of 20 percent was observed. Based on these “real-world” noise values, a threshold rejection level of 40 percent was selected to conduct the POD analysis.

Analysis

The software, PODSS Version 3, was used to generate both composite and individual inspector *POD(**a**)* estimates. A log-linear model (curve fit) was used. Based on noise measurements determined on actual hardware, a rejection threshold of 40 percent vertical screen height was established. The resulting $\hat{a}$ versus a correlation and composite POD (95-percent confidence) curves are illustrated in Figure 11 and Figure 12.

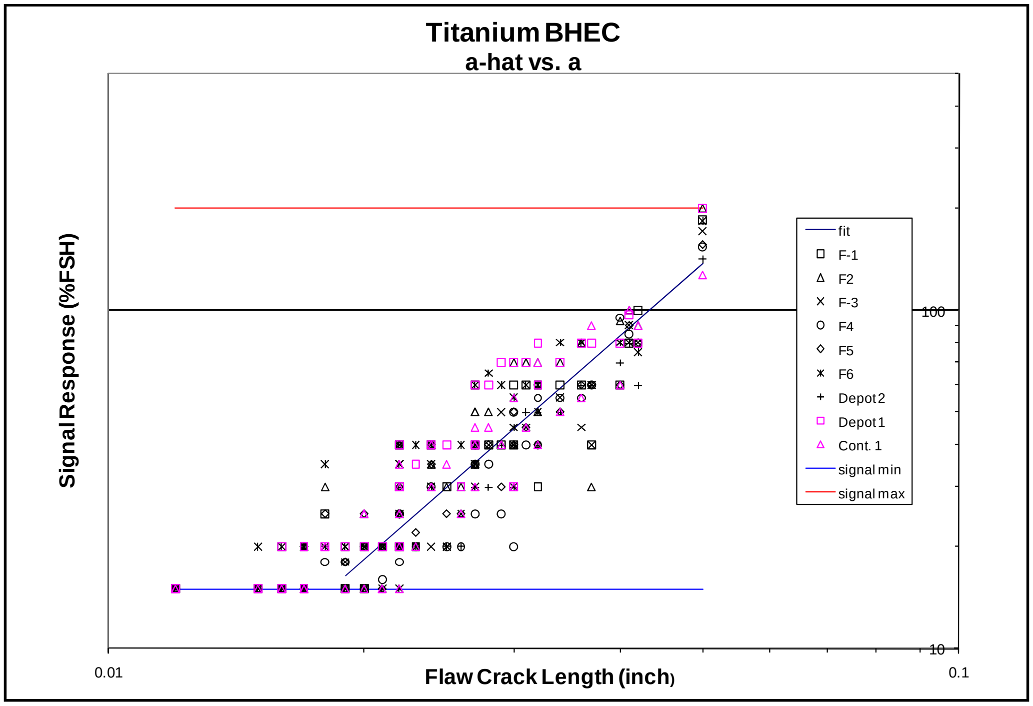

Figure 11. Example POD *â* versus *a* Plot for Mid-Bore Fatigue Cracks in Titanium by Bolt Hole Eddy Current Inspection

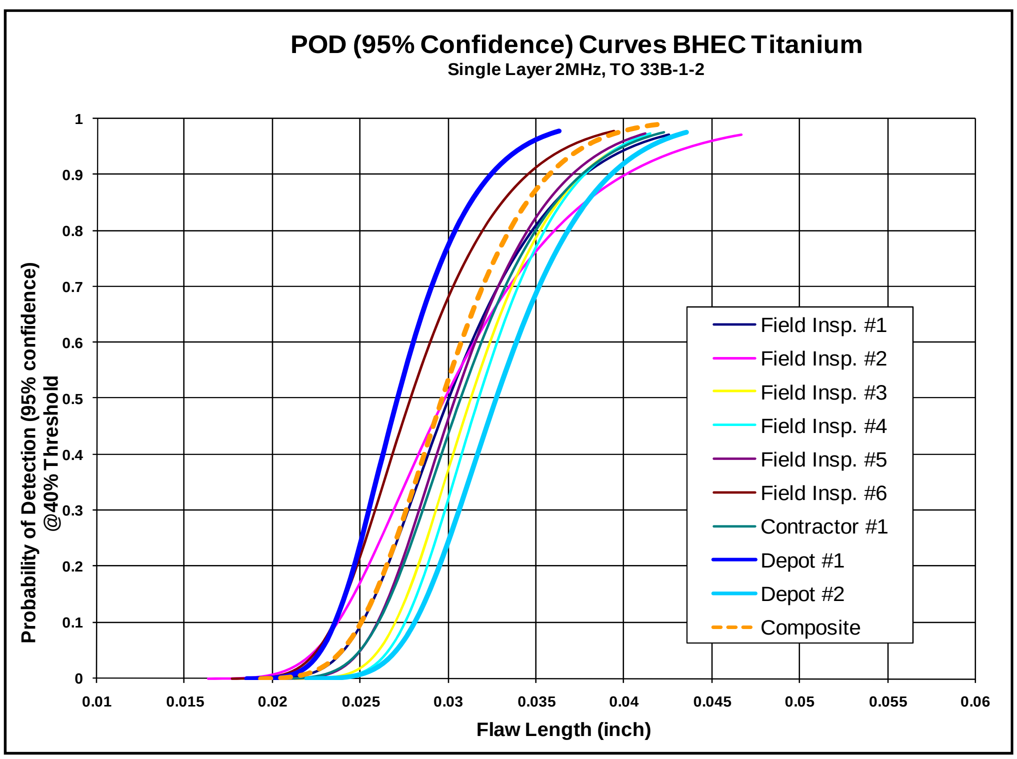

Figure 12. Example POD (95% Confidence) Curves for Detection of Mid-Bore Fatigue Cracks in Titanium by Bolt-Hole Eddy Current Inspection

6.5 Capability Estimation Using Existing Data Sets

The most cost effective approach for establishing inspection capability is through the use of existing POD data. Baseline capability (a_{NDI}) values have been established for standardized USAF eddy-current and fluorescent penetrant inspection processes performed in accordance with T.O. 33B-1-2. These values, defined within the Aeronautical System Center Structures Bulletin EN-SB-08-012, *Nondestructive Inspection Capability Guidelines for United States Air Force Aircraft Structures*, should be used when empirical data is lacking. A number of other sources for generic NDI capability data exist [11-16]; however, application of such estimates to other inspections should be done with **extreme caution**. A complete understanding of the variables and assumptions used to establish these estimates is critical. Unfortunately, many resources do not provide sufficient detail or provide the raw inspection data required to translate estimates to other applications. For example, estimates established using Level 4 sensitivity fluorescent penetrant are not directly applicable to Level 2 sensitivity fluorescent penetrant processes. Similarly, estimates generated for 45 degree shear wave ultrasonic inspections will not be directly applicable to 70 degree shear wave ultrasonic applications.

If all the variables associated with a particular capability estimate are known and the inspection data used to generate these estimates are available then it may be possible to use the existing data and apply corrections or ***transfer functions*** to establish reasonable estimates. Approaches for applying transfer functions to $\hat{a}$ versus a data are discussed further in Sections 6.5.1.

If existing data is available, yet significant variance exists between candidate and comparative inspection process in terms of flaw type, structural/material detail or inspection parameters, then one must:

1. Assess the factors which may result in variance between the two test cases
2. Determine how the variance may be determined through limited experiment
3. Conduct experiments to quantify the variance
4. Apply resulting correction factors or transfer function to the existing data.

6.5.1 Guidelines for Using Existing Data

To apply existing POD data sets to new inspection applications one must have a complete understanding of all factors used to develop the original data set as well as the factors that may influence the capability of the inspection application under consideration. The major factors that should be defined include, but are not limited to:

1. Equipment *(e.g., Manufacturer A vs. Manufacturer B)*
2. Probes/Transducer/Sensor Types *(e.g,. 45 degree shear wave vs. 70 degree shear wave)*
3. Inspection Materials *(e.g., Level 2 vs. Level 2 sensitivity penetrant)*
4. Part Material Type (*e.g., 7075-T6 vs. 2024-T3 Aluminum*)

5. Flaw Type *(e.g., fatigue crack vs. stress corrosion crack)*
6. Part Geometry *(e.g., flat surfaces vs. edges)*
7. Inspection Access/Human Factors *(e.g., inspection on top of wing versus inside wing fuel cell)*
8. Scan Plan *(e.g., large area open surface scan vs. scan around fasteners)*
9. Inspector Experience/Training *(e.g., 3 Level vs. 7 Level or Level I vs. Level III).*

If two or more major factors differ between the existing data set and the inspection under evaluation then it may be difficult to use existing data without rerunning at least a significant portion of the experiment. Moreover, if the particular factor could result in additional random variance, a simple correction factor again may not be applicable. However, if only a couple of factors differ that could result in a shift in detectability without additional random variance; it may be possible to achieve reasonable estimates by applying simple correction factors to the existing data sets.

The following discussion provides an example for applying a single parameter transfer functions to existing $\hat{a}$ versus a data sets. Additional guidance for applying transfer functions to hit-miss data sets and multiparameter transfer functions will be provided in future updates to this document.

6.5.1.1 Example: Single Parameter Transfer to $\hat{a}$ *vs. a* Data

Example: Single Parameter Transfer

First, assume an inspection is to be performed using the same inspection process as described in Section 6.4.2.2. The same written procedure, equipment, inspector experience and setup procedures were applied to detect the same flaw types in the same material with similar part geometries. However, with this inspection a larger notch was used to calibrate the inspection system resulting in overall reduced inspection sensitivity. Fortunately, the original POD experiment used the $\hat{a}$ versus a approach and therefore the raw data which defined amplitude versus flaw size relationship is available.

Through simple measurement of the instrument gain at each calibration point, it was determined that the new inspection calibration process results in a 4 dB reduction in inspection sensitivity. Given that the original $\hat{a}$ data is available, the individual amplitude values for each detected flaw can be reduced by 4 dB using the equation:

$$\Delta dB = 20\log(A1/A2) \qquad (1)$$

Or

$$A1 = A2 * e^{\Delta dB/20}, \qquad (2)$$

where: A1 is the new flaw amplitude, and A2 is the original flaw response amplitude

Once the signal amplitude has been modified for each of the original inspection data points, the revised or transformed POD(***a***) estimate can be calculated (Figure 13 and Figure 14).

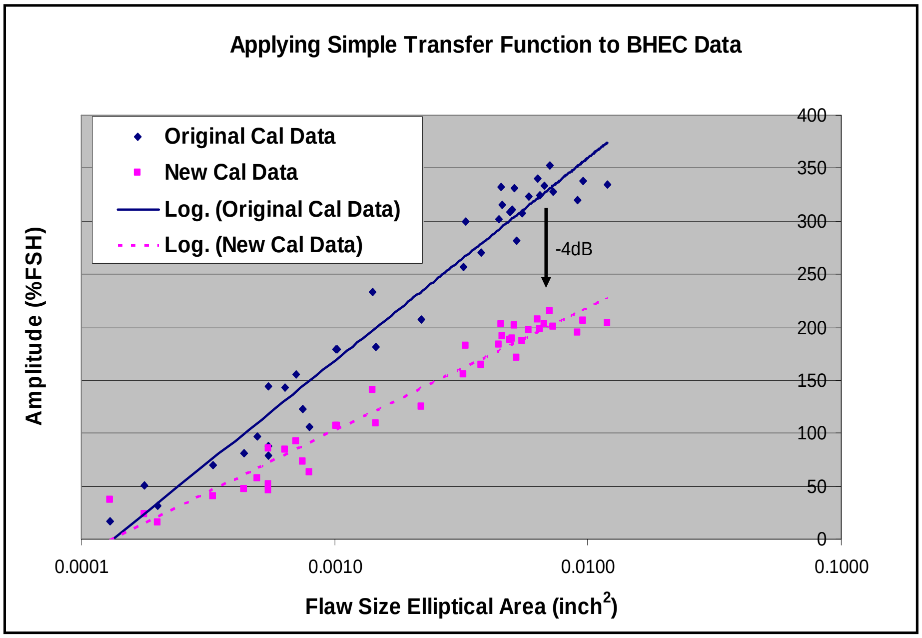

Figure 13. Example of Single-Parameter *â* versus *a* Transfer for Estimating Bolt Hole Eddy Current Inspection Capability for 7075-T6 Aluminum

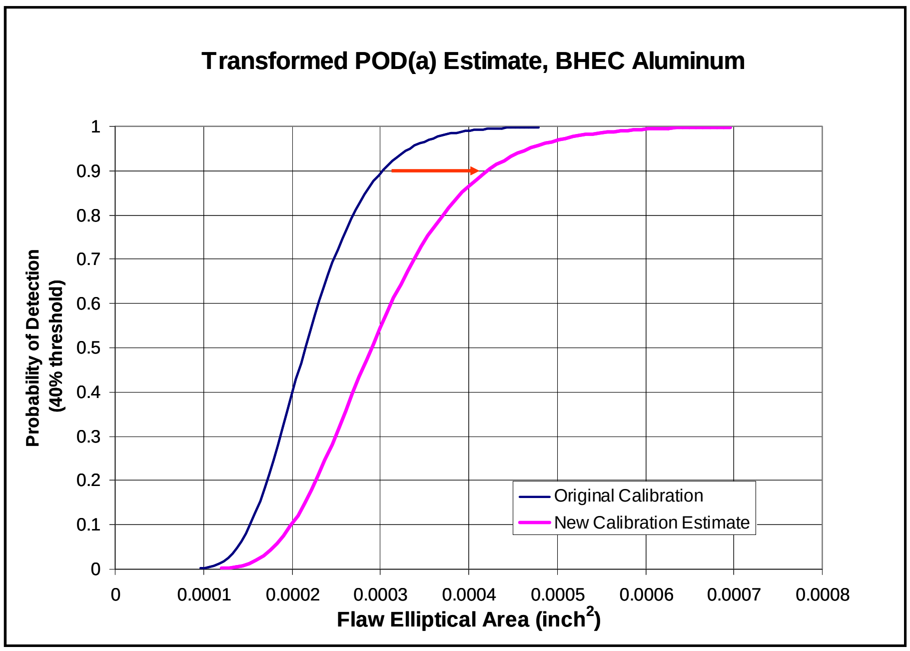

Figure 14. Resulting Transferred POD Curves for Bolt Hole Eddy Current Inspection for Corner Fatigue Cracks in 7075-T6 Aluminum

6.5.2 Guidelines for Applying Qualitative Adjustment Factors to Capability Estimates

Inspection capability is significantly affected by multiple human factors induced variances. To address these variances the responsible NDI Level III in coordination with the responsible structural engineer must take into consideration the following factors when estimating application specific NDI capability:

Inspection Area Access:

- The area of inspection must be visually and physically accessible.
  - Visual Access: Suspect defect location must be directly visible to the inspector without the use of visual aids such as a mirror or borescope
  - Physical access: Inspection location must accommodate the inspector and the inspection sensor (i.e., probe, transducer) and allow for unencumbered manipulation of the sensor by the inspector. Unless aided by a second inspector, the inspector must have direct visual access to the inspection unit display while manipulating the sensor.

Inspection Area Focus:

- Inspections must be focused or subdivided into zones that can reasonably be accomplished by one inspector in a one-hour time frame.
  - Open inspection surface areas must be focused or broken into individual zones less than 4 in^2.
  - Edge, radius or other linear inspections must be focused or broken into individual zones less than or equal to 2 linear feet
  - Fastener inspections or other discrete inspection locations must be broken into zones with 10 or less total inspection sites
  - It is recommended that inspection data recording sheets be developed and incorporated into procedures to guide focused inspections as necessary.

Inspection complexity: Procedures of a complex nature shall require Task Specific Training.

Other Factors:

- Human: monotony, fatigue, inspection frequency, training currency, etc.
- Environmental: lighting, ambient temperature conditions, etc.

If the above factors are judged to have a significant effect on an inspection the assumed $\boldsymbol{a_{NDI}}$ should be adjusted. The responsible NDI Level III should evaluate the procedure and apply an appropriate “inspectability factor”. The inspectability factor is assigned based on a <u>qualitative</u> assessment of inspection difficulty and human factors challenges only. Recommended inspectability factors $(\boldsymbol{\mu})$ are summarized below. The assumed method specific $\boldsymbol{a_{NDI}}$ should be adjusted by multiplying by the appropriate factor. Example scenarios for the use of each factor are provided for guidance only. It is possible that a combination of inspection conditions would warrant application of larger factor than defined below.

Inspectability Factor (μ) = 1 Inspections that are readily performed with no significant human factors challenges.

Inspectability Factor (μ) = 1.25
1. Inspections that are considered mildly difficult where no task specific training is provided
2. Inspections with mildly challenging access, but with direct line-of sight and focused on a limited inspection zone
3. Inspections which require between 1 to 2 hours to complete.

Inspectability Factor (μ) = 1.5
1. Inspections that are considered difficult where no task-specific training is provided
2. Inspections with challenging access, but with direct line-of-sight
3. Inspections that moderately exceed the inspection zone size, inspection time-frame or focusing criteria.

Inspectability Factor (μ) = 2.0
1. Inspections that are considered extremely difficult where no task-specific training is provided
2. Inspections with extremely challenging access difficulties
3. Blind or semi-blind inspections with limited line-of-site to inspection zone
4. Inspections that far exceed the inspection zone size and/or focusing criteria.

6.6 Capability Estimation Using Limited Data Sets

Currently, inspection capability estimates for most SOF inspections are not supported or validated empirically in the manner described in MIL-HDBK-1823. As stated previously most estimates of a_{NDI} have been based on best guess engineering estimates. In many cases, performance of exhaustive MIL-HDBK-1823 experiments is cost prohibitive as specimens sets are expensive to manufacture, POD experiments can be very costly and time consuming in terms of manpower, furthermore, POD experiments are often focused on a specific geometry and/or material and are difficult to translate to other materials.

A method for estimating inspection capability with much smaller data sets is described below. This method uses a limited sampling approach for inspection processes where a relationship can be established between flaw size and flaw response, i.e., high or low frequency eddy current, shear-wave ultrasonics. This approach is best applied where human induced variance is minimized through the use of scanners or fixturing.

Master Gage Fabrication
The approach begins by determining the target capability size requirement in terms of the required a_{90} or $a_{90/95}$ value. Fabricate a master standard that represents the structural geometry to be inspected. The master gage must match the target inspection in terms of materials, stack-up thicknesses, fasteners, coatings, etc. Fabricate the master standard

with three or more "calibration" artifacts. The range of target flaw sizes must span above and below the target capability requirement. A recommended approach is as follows:

- Flaw A Size: ~ $\boldsymbol{a}_{NDI}$ / 2
- Flaw B Size: ~ $\boldsymbol{a}_{NDI}$
- Flaw C Size: ~ $\boldsymbol{a}_{NDI}$ x 2

It is important that a measurable response can be achieved from all three flaws.

Defect Specimens

Fabricate ten or more representative defects into representative structural geometry. The range of flaw sizes must span the same range as the master gage. The flaws must be randomly located with as many unflawed sites as flawed sites.

Measurement of Flaw Response

Develop a detailed inspection procedure in accordance with the requirements of Section 5.0. Calibrate the instrumentation in accordance with the calibration procedure. Measure and record the response from the master gage target flaws. Perform an inspection of all defect specimens in a random order. Measure and record the amplitude response from any observed flaw indication. Perform a total of seven or more independent inspections using a minimum of seven representative inspectors (if available). Record all measurements in tabular form. Using an X-Y plot, establish whether or not a crack size (X-axis) versus signal response (Y-axis) relationship exists.

Measurement of Application Noise

Using the detailed inspection procedure, perform several (seven or more) independent inspections on actual structural hardware. If inspections are to be conducted on-aircraft, perform inspection on the actual structure on the aircraft in exactly the same conditions that the inspections will be performed. Recommend obtaining noise measurements from at least three aircraft, or if structures are performed in the disassembled condition, at least seven components.

Noise measurements should be performed in representative locations that are not expected to contain a flaw. Measure and record the peak noise at each inspection location.

The peak noise value used for analysis is the greatest peak noise value observed from all measurements.

Analysis

Populate the data sheet treating each inspector data set as an independent inspection (i.e. separate columns). From the seven independent inspection data sets (minimum of 84 data points, 7 inspectors x 12 flaws), generate composite $\boldsymbol{a}_{90}$ and $\boldsymbol{a}_{90/95}$ curves using a USAF accepted POD software and an $\hat{\boldsymbol{a}}$ versus $\boldsymbol{a}$ model. (See Section 6.4.2).
Select a rejection threshold to establish a **minimum** 2:1 (signal/noise) ratio, 3:1 is recommended.

Interpreting the Data
Evaluate the resulting analysis using the following guidelines:

First, in order for the data to be valid the following criteria must be met:
- A relationship must exist between flaw size and flaw response.
- The flaw response must continue to increase with flaw response or reach saturation.

If both criteria are met then evaluate the results to determine the largest flaw size missed by any inspector. The final $a_{90/95}$ capability estimate should be at least 2X the size of the largest flaw missed regardless of the POD calculations.

If the capability estimate is less than the required a_{NDI} value then there is some confidence the capability can be met with appropriate controls. If the estimate is greater than the required a_{NDI} value then either the inspection process must be improved or the requirement adjusted.

The use of transfer functions may be required to correct for parameters that could not be simulated within the full specimen set. These variations could include but are not limited to flaw characteristics (i.e. EDM notches vs. fatigue cracks), material variations (7075-T6 aluminum vs. 2024-T3 aluminum), etc., (See Section 6.5.1.1).

6.6.1 Example: Capability Estimation Using Limited Data Sets

An inspection kit and procedure were developed to inspect the edges of fracture critical titanium wing attach lugs for fatigue cracks. The kit consisted of a pivoting head eddy current probe specifically designed to scan along edges and reduce human induced scan variance. The kit also included references standards containing electro discharge machined (EDM) slots positioned on one edge. Three slot sizes (0.040 inch, 0.060 inch and 0.080 inch) were used for calibration and sensitivity check. The inspection required an $a_{90/95}$ inspection capability of 0.100 inch (threshold). A target demonstration goal of 0.060 inch was established.

A detailed inspection procedure was developed and validated. To estimate the inspection capability, a series of five Ti-6-4 rectangular bars were manufactured with dimensions 14 inches (long) x 1 inch (wide) x 0.25 inch (thick). A series of fifteen fatigue cracks were grown within the edges of the bars using constant amplitude three point bending. The crack sizes ranged from 0.020 inch to 0.120 inch. A uniform distribution was used. The cracks were randomly located along the bar with no more than one crack per edge and no more than three cracks per bar.

The kits, procedures and specimens were transported to a USAF field base were inspection data was gathered by field level inspection personnel.

Each inspector followed the calibration procedure utilizing reference standards to calibrate the instrument and edge probes to the required inspection sensitivity. After

calibration, each inspector performed an inspection of each edge of each bar. If an indication was identified, its location and amplitude was recorded on the inspection data sheet.

Multiple inspections were performed on-aircraft using the inspection kit and written procedure to measure typical peak noise levels. The observations indicated a peak noise of 20 percent peak-to-peak.

The resulting inspection finds were plotted and a POD estimate generated using the PODSS Version 3 software. A log $\hat{a}$ vs. log a model was used. An inspection threshold of 40 percent peak-to-peak was selected. The resulting a vs. a fit data and composite POD(a) and POD(95-percent Confidence) curves are presented in Figure 6-8 and Figure 6-9 respectively.

The resulting individual inspector $a_{90/95}$ values ranged from 0.030 inch to 0.054 inch with a composite value of 0.037 inch. Based on these results it was determined that both the goal and threshold $a_{90/95}$ requirements could be met by the inspection approach.

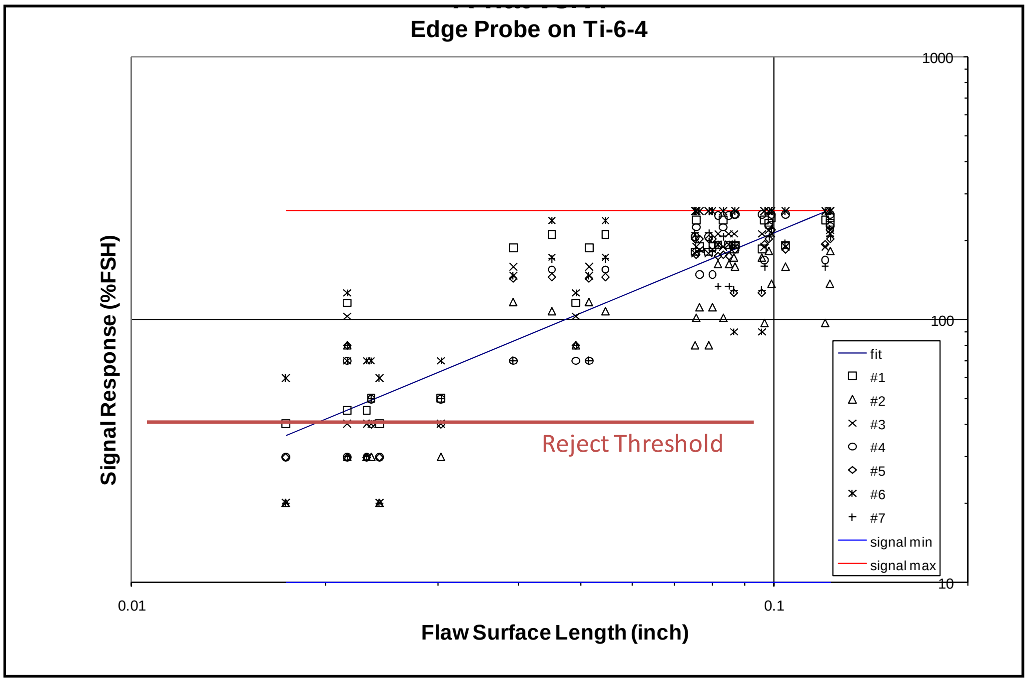

Figure 14. Resulting $\hat{a}$ versus a Curve Fit for Eddy Current Inspection of Titanium Edges using Tailored Probe

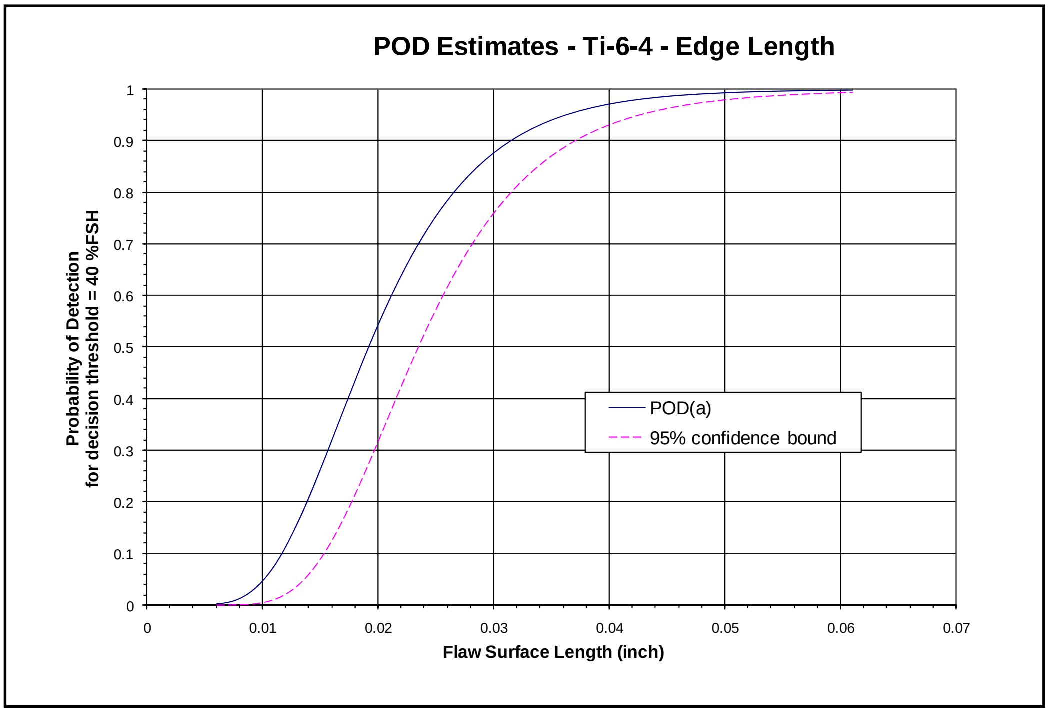

Figure 15. Resulting Composite POD(*a*) and 95-percent Confidence Curves for Eddy Current Inspection of Titanium Edges using a Tailored Edge Probe

7.0 NDI Procedure Qualification

7.1 Introduction

The use of qualified NDI procedures is essential to maintaining the structural integrity of USAF aircraft, commodities and other support systems. Numerous USAF Instructions and Technical Orders require a validation and/or verification process to qualify NDI procedures. This process is often referred to as validation/verification.

7.2 Purpose

This guide establishes a standardized AF NDI Procedure Qualification Process. The implementation of this process will enhance the safety of AF systems that rely on NDI by further ensuring the performance capability and reliability of NDI procedures.

7.3 Scope

The qualification process defined by this guide applies to all new or modified NDI procedures whether developed organically or by contractual means.

7.4 Responsibilities

It is the shared responsibility of the Air Logistics Center (ALC) NDI Program Manager and the responsible System Program Office (SPO) engineer to ensure NDI procedures are qualified prior to publication, distribution and use (Ref. AFI 21-105). The ASIP Manager is the designated responsible engineer for aircraft specific procedures. Funding for procedure validation and verification activities is the responsibility of the applicable System Program Office. Scheduling of verification activities at depot or field level facilities is the responsibility of the applicable SPO.

7.5 General NDI Procedure Requirements

- All nondestructive inspections must be performed in accordance with written technical instructions approved by the responsible ALC NDI Program Manager. The NDI Program Manager may designate other Level III certified individuals as procedure approval officials.
- NDI procedure content must meet the requirements of MIL-DTL-87929C and any additional requirements contained in this guide.
- NDI procedure qualification must be accomplished, documented and approved per this guide prior to procedure publication, distribution and use.
- For contractual NDI support, all procedures must be approved by a method specific Level III certified individual designated per the contractor's written practice. Deviations to this requirement must be approved by the responsible System Program Office. All contractor developed procedures should undergo AF Level III review prior to release.

7.6 NDI Procedure Qualification Requirements

The AF NDI Procedure Qualification Process is comprised of two phases; Procedure Validation and Procedure Verification. The scope and objectives of each phase are defined below. Phase objectives and attributes are intentionally broad to accommodate differences in local ALC practices. The criteria are adaptable to many scenarios and are meant to guide the qualification process toward a common set of objectives, not to rigidly dictate how results are obtained. Concurrent work in both phases is expected and it is also anticipated that certain steps will require multiple iterations prior to final procedure qualification.

Phase I: Procedure Validation

Validation is the process of demonstrating that the inspection equipment, procedures and standards meet the customer's inspection requirements with the intent to correct deficiencies before proceeding to the final verification process. Procedure Validation starts as soon as the inspection need is identified. During validation the NDI technique is expected to progress from initial concept to a written draft procedure. Progress will occur predominantly through laboratory environment testing. Software-modeling, open-specimen trials and prototype demonstrations are the principal means of testing expected during this phase. Validation normally concludes with procedure performance on simulated or actual components to the satisfaction of the responsible Level III and the ALC NDI Program Manager.

Procedure validation must as a minimum accomplish the following objectives and be documented per the appropriate Qualification Checklist.

- Collect and analyze supporting data.
- Determine appropriate method, equipment and technique parameters.
- Determine requirements for unique reference standards to effectively control set-up variability.
- Determine appropriate technician skill-level for reliable procedure performance.
- Determine appropriate component removal and surface preparation requirements necessary for adequate access.
- Design/manufacture test specimens containing actual or simulated discontinuities.
- Design/manufacture prototype support equipment.
- Produce a draft technical procedure.
- Demonstrate procedure feasibility to responsible Level III.
- Approve the procedure ready for formal verification.

Phase II: Procedure Verification

Verification is the process of fully demonstrating the inspection process, equipment, procedures and standards meets the customer's functional and performance requirements, as executed by the representative inspectors within the intended operational environment. Portions of Procedure Verification may be performed in conjunction with Procedure Validation, but typically the verification phase will immediately follow the conclusion of procedure validation. A primary goal of the Verification Phase is to finalize written technical data. This will normally be accomplished through a combination of blind-specimen trials and formal procedure demonstrations in a production environment. The verification process must prove the suitability of an NDI procedure to perform its intended purpose to the satisfaction of the end-user, the responsible Level III, the ALC NDI Program Manager and the responsible SPO Engineer.

Procedure Verification must as a minimum accomplish the following objectives and be documented per the appropriate Qualification Checklist.

- Ensure the procedure is thorough, understandable and logically written.
- Ensure the procedure is understood and executable by the lowest skill-level projected for production use.
- Ensure the specified equipment performs as expected and is readily available to the intended end-user.
- Ensure the specified part preparation techniques are logical and can be accomplished as written.
- Demonstrate the procedure meets ASIP expectations for detection capability and false call propensity (See **Note** below).
- Determine the need for specialized personnel training or certification.
- Determine the estimated inspection process man-hours.
- Account for human factor and environmental variables as necessary.
- Document verification per the appropriate Qualification Checklist.
- Approve the procedure for publication, distribution and use.

Note: If approved by the responsible SPO Engineer and ALC NDI Program Manager, procedure detection capability may be based on similarity to previously documented verifications. If applicable, the use of validated transfer functions and models may be utilized to adjust similar capability estimates.

7.7 Methods of Procedure Verification

Procedure Verification may be accomplished by one of three methods; Performance, Simulation or Analysis. Each method is defined below. Verification by Performance is always the preferred method. The NDI Program Manager and responsible SPO Engineer can approve Verification by Simulation or Analysis, but the intent is to keep the use of these methods at a minimum. Justification for alternate methods of verification must be provided in writing by the responsible NDI Level III and filed with the procedure development documentation.

Verification by Performance: Verification by Performance requires the written technical instructions to be successfully carried out on a production configured aircraft, component or commodity in a maintenance environment. Verification by Performance must always be accomplished by the lowest NDI skill-level anticipated to perform the inspection in production.

Verification by Performance is the most stringent and potentially the most costly verification method. Although the primary focus of verification is the NDI technique, all aspects of the procedure require verification (i.e., surface prep, component removal). As such, verifications often involve many mechanic, technician and engineering man-hours. If not properly planned and scheduled, verifications can result in production interruptions or delays. The procedure developer, in conjunction with the responsible SPO Engineer, must plan for performance verifications early in the process to avoid production interruptions and extra costs.

- All NDI procedures associated with SOF structure must be Verified by Performance.
- When deemed necessary by the responsible SPO Engineer or ALC NDI Program Manager, NDI procedure performance must be formally demonstrated through statistically-valid, POD experiments.

Verification by Simulation: Verification by Simulation must be based upon first-hand, working knowledge of the production configured aircraft, component or commodity and the proposed NDI procedural requirements. Verification by Simulation may only be conducted if justified and approved by the responsible SPO Engineer and the ALC NDI Program Manager. Typical instances where Verification by Simulation may be considered include: 1) revision of an existing qualified procedure to expand the area of interest, 2) implementation of an existing qualified procedure to similar structure elsewhere on the aircraft, 3) when POD data is available and can be directly correlated to the inspection requirements at hand, and 4) urgent situations where time constraints do not permit full Verification by Performance to be accomplished.

Follow-up Verification by Performance should always be considered when Verification by Simulation is utilized. If procedural deficiencies are discovered during the follow-up verification, the inspection should be re-issued with necessary improvements.

Verification by Analysis: Verification by Analysis is the least stringent and most risky verification method. This method should only be considered for use in extremely urgent or emergency situations. Verification by Analysis must be based on valid engineering assumptions gained through direct experience and comparison with similar procedural performance data. Verification by Analysis is only allowed if approved by the responsible SPO Engineer and the ALC NDI Program Manager.

Follow-up Verification by Performance should always be considered when Verification by Analysis is utilized. If procedural deficiencies are discovered during the follow-up verification, the inspection should be re-issued with necessary improvements.

7.8 Technique Specific NDI Procedure Qualification Requirements

In addition to the general objectives defined above, each method has additional qualification requirements specified by the appropriate checklists in Appendices A through F. The information required of each checklist is specific to that method, with the exception of the Phase II checklist which is applicable to all methods. When properly filled out, the checklist provides the majority of the necessary qualification report data. The checklists should be permanently filed with the procedure development archives.

- Appendix A: Phase I, Penetrant Testing (PT)
- Appendix B: Phase I, Magnetic Particle Testing (MT)
- Appendix C: Phase I, Eddy Current Testing (ET)
- Appendix D: Phase I, Ultrasonic Testing (UT)
- Appendix E: Phase I, Radiographic Testing (RT)
- Appendix F: Phase II, All Methods.

8.0 Best Practices for Equipment Controls

8.1 Equipment Procurement, Control and Maintenance

The following industry and DoD Best Practices for NDI equipment procurement, control and maintenance were identified by the USAF NDI Benchmarking study.

BEST PRACTICES

- ***Assign all aspects of the NDI Support Equipment Procurement and Management Program to a Branch/Division. This a recommended Best Practice from the US Coast Guard and Delta Airlines.***
- ***Perform NDI Support Equipment Requirement Analysis before any AF wide equipment procurement is conducted and implemented. This is being practiced by NAVAIR in their equipment procurement program. In addition to several cost benefit analysis tools associated with this requirement analysis performed prior to procurement, other investigative actions such as trade studies, prospective user's surveys and interviews, legacy system capability evaluations should be conducted.***
- ***Send NDI equipment needing repairs directly from a unit NDI lab to a source of repair contractor. This is a practice commonly utilized in the AF depot, the Navy, and commercial airlines (Delta). Sending NDI equipment needing repairs to a warehouse for staging while waiting to be shipped to the contractor incurs additional expenses while denying the labs the use of their equipment for long period of time.***
- ***Assign a Equipment Manager/Specialist to each MAJCOM who understands the priority and requirements of each Units/labs to the mission of the MAJCOM so prompt assignment/transfer of equipment could be effectively implemented.***

8.2 Requirements for Periodic Process Control Checks

Requirements for periodic process control checks are documented within T.O. 33B-1-1 and T.O. 33B-1-2. The guidance contained within these technical manuals are essentially Best Practices for conducting method specific process control checks within Air Force NDI laboratories. The following are additional Best Practices identified by the USAF NDI Benchmarking study.

BEST PRACTICES

- ***Industry standards and technical manuals should be cited with laboratory specific process control procedures.***
- ***Frequent audits of the process control program should be conducted by external experts.***

8.3 Requirements for Periodic Instrument Calibration/ Performance Checks

The following Best Practices related to Instrument Calibration and Performance Checks were identified by the USAF NDI Benchmarking study.

BEST PRACTICES

- ***Consult industry standards and technical manuals for guidance i.e., ISO 10012-1, ANSI/NCSL Z540-1, T.O. 33B-1-1, etc.***
- ***Understand the process and calibration requirements of subject instruments.***
- ***Seek guidance from dependable and experienced persons or a company that performs instrument calibration and performance checks.***

8.4 Requirements for sensor and reference standard master gauging

The following Best Practices related to sensor and reference standard master gauging were identified by the USAF NDI Benchmarking study.

BEST PRACTICES

- ***Consult industry standards and technical manuals for guidance.***
- ***Understand the process and requirements for sensor and reference standard master gauging.***
- ***Seek guidance from dependable and experienced persons or a company performing sensor and reference standard master gauging.***
- ***Master gauging is important when the standard is not NIST traceable or is made from actual part hardware.***
- ***Consider usage and wear rates.***
- ***Implement periodic visual examination to inspector for damage or wear.***
- ***Consider logistics and supportability of matched probes and standards.***

9.0 Best Practices for Training and Certification

The USAF requires that all depot civilian inspectors be trained, qualified and certified in accordance with the National Aerospace Standard NAS-410 and AFMCI 21-108. NAS 410 is essentially an aerospace industry consensus BEST PRACTICE for insuring a competent and effective NDI workforce.

Efforts are underway to attempt to merge the existing civilian and military NDI qualification programs to ensure that inspection conducted at any USAF location are performed by NDI professionals of comparable experience and qualification.

Apart from the requirements defined within NAS-410, the USAF NDI Benchmarking study identified a number of commercial and DoD Best Practices that should be considered when implementing an effective NDI Training and Certification program:

9.1 Training Organizations

Many facilities, due to budgetary restrictions, utilize a single training group that provides initial and refresher training on anything from fire extinguisher use to CPR to NDI. At the very least, the NDI may be taught separately but along with the other mechanics classes such as jet engine familiarization or interpreting engineering drawings. Although AFMCI 21-108, *Maintenance Training & Production Acceptance Certification Programs (PAC)*, states that NDI is a skill so specialized it requires formal training and proficiency demonstration, there is no actual requirement that the NDI training be provided by an organization dedicated solely to NDI. It is strongly recommended that NDI training be provided by a dedicated organization.

Location of the organization is also vital to providing the level of instruction necessary. It is recommended that the training organization be located within the maintenance organization for two reasons:

1. <u>Control of the instruction material</u>. If the training organization is located within the maintenance organization, then it is much easier to make changes to the material to reflect changes in equipment, procedures, etc. Although the courses themselves must meet AF requirements and changes must be made through the proper channels, it is still much easier to make changes and updates when the instructor is located within the same group. If the instructor is located in another group from the subject matter experts (SMEs) then there will be a certain amount of back and forth that will cause unnecessary delays.

2. <u>Flexibility</u>. When the training organization is co-located within maintenance, then they share some amount of the corporate vision. This allows for more flexibility when it comes to providing training in two ways. If the training organization resides in a separate organization, such as human resources, etc., then they have their own corporate mission. That mission may be to provide training, but they will also have other customers. The first advantage is it allows for wide variations in class sizes. If there is a need for training

for a single student, then training for a single student can be provided. There have been instances where students have been delayed for six months waiting for enough students to fill the minimum class size. Secondly it allows for a faster reaction time when it comes to scheduling classes. If a class is needed immediately, then one can be scheduled immediately and not delayed as it is worked into or around the overall training schedule.

Although it is recommended that the training organization be located within the maintenance organization, it is also recommended that it not reside within any of the production groups, but in a group such as the support group. This will provide the required separation that comes with using an outside agency, but also provide some level of protection from production pressure to push and pass students through.

9.2 NDI Instructors

It is recommended that the instructors providing training be dedicated instructors that possess a Level III certification. It is further recommended that, in order to qualify for instructor, the employer have minimum in-method experience. It is a requirement that anyone presenting, teaching, or instructing from formal class room material shall be a certified AF instructor. Each of these will be discussed in detail below.

BEST PRACTICE

***Training Organizations* - Dedicated Level III training teams are recommended for all NDI instruction at depot facilities. Dedicated NDI training organizations allow the full attention of the instructors to be focused on improving NDI technician performance.**

NOTE: AIA NAS-410 does not require the instructor or be a Level III, only that the responsible Level III designate or approve the instructor.

1. Dedicated Instructors. It is recommended that NDI instructors providing formal classroom training be dedicated solely to NDI. To teach only NDI, requires the instructor to be extremely knowledgeable in; all five NDI methods, materials, math, and the equipment used in each method. Furthermore, as will be discussed under task specific training, the instructor will need to be familiar with a wide variety of practical applications. To require an instructor, or multiple instructors, to know NDI well enough to impart this information and teach other courses will lead to the NDI students not getting the level of instruction they need or deserve.

When using a dedicated NDI instructor it is far easier to meet the needs of the customer in terms of class scheduling and class tailoring to meet the specific needs of the organization.

2. Level III Certification. Few skills require the in depth technical knowledge and skill set that NDI requires. In order to explain the NDI theory and adequately answer the technical questions posed by the student, it is strongly recommended that the NDI instructors be Level III certified in the method that they are teaching. There are

economic considerations that make this recommendation difficult to implement. Namely, Level III certified individuals are usually highly trained and experienced personnel and therefore are probably higher graded than other instructors. The costs associated with the additional training and experience requirements are justified when compared to the other additional expenses found in NDI such a courseware development and the equipment needed for NDI training that is not usually found with other training.

One other option is to use Level III's other than the dedicated NDI instructor(s) to periodically substitute teach. The theory being that teaching reinforces ones knowledge of the subject. Therefore, as the Level IIIs rotate in and periodically teach these classes, they are becoming better at their craft.

3. In-method Experience. NAS-410 states that "instructors shall have the skills and knowledge to plan, organize, and present classroom training and practical exercises in accordance with approved course outlines." However, there is no specified requirement for in-method experience. It is recommended that the employer establish minimum in-method experience for the instructors. One suggestion is to follow the experience requirements for designated OJT providers of at least one years experience in the method at or above the Level II level.

If a Level III is used as the instructor, the Level III will have at least 1 year experience in that method and no further experience is required.

4. Certified Instructor. AFI 36-2232, AFMC Supplement 1, paragraph 1.26.1.1.2, Instructor Qualification, states "Personnel who provide formal training using a plan of instruction shall complete the Air Force Principles of Instruction (PoI) Course, or equivalent." The PoI class is taught only periodically at most bases, but is regularly taught at Sheppard AFB, and the FAA Center in Oklahoma City.

BEST PRACTICE

NDI Instructors* - *Require dedicated Level III training instructors for all NDI instruction. Require time-in-method requirements for all instructors. The amount of time will be determined by an implementation team. Time-in-method could include production, training, and teaching, writing procedures, study, or attending continuing education. All NDI instructors must meet the requirements of NAS410, AFMCI 21-108 and any local instructions.

9.3 Formal Standardized Core Training

Recent probabilities of detection (POD) studies have pointed to the possibility that standardized training may play a more critical role in the performance of inspectors than previously thought. In response, AFMC HQ has invested heavily in the development of new, civilian standardized NDI courseware so that all civilian inspectors will receive the best possible training, and all civilian inspectors will receive the same training. This courseware was built upon the classes that are being taught to the military inspectors at the AF NDI Schoolhouse at Naval Air Station (NAS), Pensacola.

It is recommended that facilities adopt a similar approach to developing NDI courseware, which includes the four following characteristics:

1. <u>Basic math refresher</u>. Three of the five method classes have a math refresher that covers the basics of NDI math, and each class also has the method specific math needed, if different. The math refresher block is between four to six hours, depending on complexity.

2. <u>POD</u>. The AFIA Eagle Look recommended that POD theory be taught to the inspectors as a way to increase visibility to the importance of ASIP, engine structural integrity programs (ENSIP), and SOF inspections. Each of the method classes contains a 4 hour block of introduction to POD.

3. <u>In-depth theory</u>. The theory used for Level I and Level II classes has been improved to include a more in-depth theory than in previous classes. The increase in inspection complexity has led to the need for a more robust class and a more knowledgeable inspector.

4. <u>Hands-on training</u>. All of the new AFMC classes are heavily reliant on hands-on training using 25 to 33 percent of the class time. The hands-on contains all process controls used by that method, practical applications, actual inspection of demonstration parts, and for x-ray, radiation safety. Equipment used for the hands-on portion must be as close to those in use as possible.

It also recommended that each facility tailor the basic courseware to better fit the needs of that facility.

It is further recommended that changes to the core curriculum be made only by, or on the recommendation of the AF NDI Executive Working Group (EWG). The regular review cycle for all courses is bi-annually, but if circumstances warrant, an out-of-cycle review (OCR) can be requested.

Another lesson-learned from the AF NDI Schoolhouse was the wash-back and wash-out rates. The Schoolhouse has wash-back rate where the students who fail are washed back to their units for further study and/or training. At some point, students who fail are washed out of the NDI skill code. Some facilities have a teach-to-pass philosophy that is

not in line with the need to determine what students are well suited to be NDI inspectors. Federal personnel laws may prohibit a wash-out without it being in the position description (PD) or core document, but the ability to wash-back a student for further study or training is recommended.

BEST PRACTICE

Formal Standardized Core Training* - *Establish and implement standardized formal core training that ensures all inspectors are getting the best training available. All formal training shall meet a minimum standard and changes to the base training must be approved and or directed by the AF NDI EWG.

9.4 Task-Specific Training

One of the recent developments coming out of the Tiger Team and the AFIA Eagle Look is the increased use of task specific training. In the past, emphasis was put on being as general as possible, generic procedures, general reference standards, etc. to meet as many inspection needs as possible with a minimum of equipment, procedures, and training. Recent developments have shown that the generic approach is inadequate in many instances. The F-22A program, for instance, has gone to a very inspection-specific approach for its inspections. This was driven in part by the need to find much smaller cracks than normal, smaller cracks than the general inspection procedures were designed to detect. Specific inspections are driving the need for task specific training.

Task specific training can include photos of the inspection area, photos and descriptions of properly prepared inspection areas, proper placement or alignment of probes, variations in structure that can occur, proper access, etc. The training can also include video or audio of the inspection.

Care must be taken such that task specific training documentation is no construed as stand-alone technical data and used as uncontrolled technical data, but only information to supplement the technical data.

The responsible Level III shall determine if the inspection is difficult or unique enough to warrant task specific training. Situations that can lead to this determination can include criticality of the inspection (e.g., SOF inspections), inspection difficulty, ergonomic challenges, or if the inspection has resulted in a missed crack in the past.

BEST PRACTICE

Task Specific Training* - *Establish and implement Task Specific Training for special inspections. Special inspections include SOF or difficult to perform inspections requiring additional training as determined by the cognizant NDI (Level III) engineer and engineering.

9.5 Refresher Training

It is recommended that refresher training be provided to coincide with the 3 year periodic recertification of the inspectors.

Some facilities have inspectors that have not been to any type of refresher training since they received initial training. This is also not in line with the current need for well trained inspectors.

Included with the AFMC HQ investment in developing the new courseware was the development of eight hour refresher courses for each of the methods.

It is also recommended that inspectors be identified that have not been to any kind of training, initial or refresher within the past 5 years. Those inspectors should be sent to a full Level II course. Eight hour refresher classes should then be repeated every 3 years.

Some concerns have been raised that teaching a refresher class immediately prior to recertification will lead to a skewing of the test scores and only demonstrate how well the student retained the refresher material and not a true measure of what the student's knowledge in the subject matter.

BEST PRACTICE

***Refresher Training* - Require refresher training as part of the three year recertification cycle to enhance and maintain inspector proficiency. A minimum number of hours to be determined by a team assigned to implement the changes.**

9.6 Training Aids

It is recommended that a bank or collection of parts to be used as training aids be assembled and maintained for the purpose of training on actual applications. It is further recommended that the collection include the inspections that pose the greatest challenge to the inspectors. This will also provide the opportunity to practice on the actual parts before performing the inspection. This is especially valuable if has been a time since the inspector has performed the inspection.

The parts should be representative of the work conducted within each facility and contain representative defects.

Agreements can usually be made with both engineering and production personnel to collect these parts if they are removed and condemned. Sometimes the removed parts are used as patterns, and then thrown in scrap barrels. Care must be taken to identify parts as condemned, or red tagged. Some facilities also required that the parts be cut, mutilated or altered in some way so they cannot be mistakenly re-installed.

One problem is that most parts are reworked until the rework limits are reached, altering the part and removing the defects. These types of parts can still be useful as electro-discharge machined (EDM) notches or fatigue cracks can be manufactured in the part within another area of interest.

The defects should be well characterized and mapped. If the parts do not already have adequate procedures, then procedures should be developed.

BEST PRACTICES

Training Aids* - *Training aids are structural components containing representative natural defects used to provide practical application of the inspection method the trainee. The training aids should be a collection of structural components representing an array of structural configurations, materials and defect types typical of the product forms inspected by the local NDI organization. All defects within the training aids should be well characterized and documented to include defect type, defect size, and expected inspection result. The library of training aids should be maintained by the local NDI training organization or by the local NDI Program manager. A method specific inspection procedure should accompany the specimens.

9.7 NDI Quality Assurance Specialist (QAS) Training

It is known that QAS within the AF often perform quality checks, quality audits, task evaluations or personnel evaluations on NDI personnel without having knowledge or experience in NDI. This leads to audits that only identified problems with the process or paperwork, and does not identify any problems with the inspection itself, the technical data, or incorrect techniques.

It is recommended that all QAS who perform audits or evaluations on NDI personnel receive NDI training from a Level III. It is further recommended that QAS who perform audits or evaluations on NDI personnel have previous experience in NDI.

Below is sample language that can be inserted into the local NDI written practice or the local Quality Manuals:

> "Quality Inspector (QI) or Quality Assurance Specialist (QAS). An individual who performs quality inspections or task evaluations. These individuals shall complete the formal classroom training for each method they will be inspecting. No certifications will be given. The individual's immediate supervisor shall ensure that training is completed."
>
> "A QAS shall complete the NDI training and structured on-the-job-training (SOJT) guide for each method for which they may be performing inspections or task evaluations, as defined in the Wing Quality Manual and Quality Assurance Plan (QAP). The SOJT guide training shall be accomplished under the direct supervision of the maintenance groups Level III. If prior to becoming a QAS, the

> individual had been certified as a Level II in that method, the maintenance group Level III may waive part or all of these requirements."

Similar language, although much broader and tailored to both civilian and military, personnel will soon be inserted in AFI 21-101.

BEST PRACTICES

***NDI Quality Assurance Personnel Training* - Require formal method training and OJT for all quality assurance specialists. Training to be provided by Level III personnel using an approved Structured OJT plan. Previous experience in the method is recommended.**

9.8 On-The-Job-Training (OJT)

Adequate and consistent on-the-job-training is absolutely critical to the development of effective inspectors.

The following recommendations are made to ensure that only qualified personnel are selected to provide OJT:

1. The OJT providers should be selected and designated for each method from a pool of qualified inspectors. Factors that should be considered are knowledge of the method, experience in that method, and the ability to transfer that knowledge and experience. For example, there may be instances where the most experienced inspector in the shop cannot adequately transfer his/her knowledge but someone with less experience may be able to better relate and transfer their knowledge.

2. The OJT providers should have a minimum of 1 year experience as a Level II in the method for which they are providing OJT.

3. The OJT providers should complete an OJT provider's course. Within AFMC, it is a requirement that anyone who provides OJT, in any skill, complete the AFMC SOJT Trainer Course (command course number CTEMAS0000500VS).

It is recommended that the responsible Level III periodically review the performance of the OJT providers to ensure adequate training.

BEST PRACTICES

***How-To OJT Training* - Require all On-The-Job Training (OJT) providers to attend a class on how to provide OJT and have at least one year as a Level II certified inspector.**

9.9 First Line (Immediate) Supervisor Training

The first line supervisor of the NDI inspectors plays perhaps the most critical role in determining the overall ability and focus of an NDI shop.

It is recommended that the first line supervisor have been previously certified as an inspector. This gives the supervisor the ability to better respond to the inspectors needs.

If the situation arises where the first line supervisor has not had previous experience, then it is recommended that they complete the Level II classroom training requirements for each method supervised. It is further recommended that any newly appointed NDI supervisor complete the required training within 1 year.

Situations also exist where an NDI inspector may be assigned to a shop that is not dedicated to NDI, such as a lean cell. In this instance where the supervisor is not an NDI supervisor, the first line supervisor should also complete the required training within 1 year of an NDI inspector being assigned to their unit.

BEST PRACTICES

***First Line (Immediate) Supervisor Training* –Require first level supervisors to complete NDI training for each method they will supervise unless previously certified.**

9.10 Practical Examinations

NAS-410 requires a practical examination, along with written general and specific examinations, as part of the periodic recertification at intervals not exceed 5 years. All three AF depots are consistent with this interval set at three years. It is recommended that the recertification interval not exceed 3 years.

However, it is further recommended that a practical exam be administered every year for each method certified. This will help indentify bad habits and tendencies more quickly before they can become entrenched.

It is also recommended that the practical exam incorporate, when possible, safety-of-flight structure with representative flaws and representative flaw sizes.

BEST PRACTICES

***Practical Examinations* - Mandate annual practical examinations for each technique and/or method. Practical examination for safety-of-flight inspections should be constructed such that the examination qualitatively measures the ability of the inspector to reliably detect flaws of the required size. Utilize standardized test samples for ALC wide practical examinations**

9.11 Random Proficiency Assessments

It is recommended, in addition to quality audits, that random, over the shoulder proficiency assessments be performed.

These assessments are performed by the Level III personnel to determine inspector skill level, identify any bad habits or tendencies, and provide a one-on-one training opportunity if additional training is needed. They are unannounced, random, over-the-shoulder observations of the entire inspection.

It is recommended that these assessments not carry the threat of adverse actions if mistakes are found, unless extremely serious or intentional. It should be understood by both the inspector and Level III that these are learning opportunities. Experience has shown that if the learning opportunity approach is taken, inspectors are open to the additional training and even look forward to the assessments.

BEST PRACTICES

***Random Proficiency Assessments* – Conduct random inspector proficiency assessments to assess inspector skill level or deficiencies over and above the quality auditor function. Random assessments should be conducted by Level III personnel.**

9.12 Retraining Requirements

It is recommended that if an inspector fails an exam, particularly the practical exam, the examiner provides a written statement to the training leader or supervisor with reason for failure, if known, and any recommended additional training. Once the additional training has been accomplished, the training leader or supervisor provides the examiner with a written statement that the training has been accomplished before the inspector is rescheduled for the exam.

BEST PRACTICES

***Retraining Requirements* - Establish and implement re-training requirements for inspectors that fail a written or practical examination. The amount of additional training could be dependent on the reason for the failure.**

10.0 Effective Organizations

A strong organization is critical to sustain an effective inspection program. A number of key organizational elements can help nurture a competent inspection work force:

- An effective training and certification program must be established.
- NDI personnel must clearly understand the criticality of their work function in terms of fleet safety and mission capability.
- The organization must ensure NDI personnel are motivated and vigilant.
- The NDI organization must ensure well engineered inspections are implemented.
    - Inspection requirements must be clearly defined.
    - Suitable equipment (Instruments, probes standards) is provided.
    - Human factors are considered in inspection development.
    - Procedures are clearly documented.
- The organization provides for means of employee feedback without retribution.
- Management is proactive about addressing shortfalls in training, procedures, communication or equipment issues.
- Management provides effective oversight of all aspects of the inspection program.
- Personnel are rewarded and promoted based on successful performance.

The authors recognize that a one-size-fits all organizational structure does not exist. An NDI organizational structure, whether centralized or matrixed, must be established based on the resources available, inspection methods employed and product forms, and production requirements. As such, no attempt is made to recommend specific organization schemes within this document.

Based on the USAF NDI Benchmark study findings a number of BEST PRACTICES related to USAF NDI specific organizational and managerial functions were identified.

10.1 Organizations

10.1.1 NDI Performing Organizations

The USAF NDI Benchmarking study identified a number of commercial and DoD Best Practices that should be considered:

BEST PRACTICE ***NDI organizations should be located outside of the direct chain of command for the production end item. This removes direct production pressure from the inspector and first level management. This is applicable to both depot and field NDI organizations.***

10.1.2 NDI Engineering Organizations

<u>BEST PRACTICE</u> ***Whether dispersed or consolidated, any NDI organization or NDI personnel performing engineering or technical duties should have reporting responsibilities to the ALC Chief Inspector or ALC NDI Program Manager.***

10.1.3 Planners, Schedulers

Planning and scheduling organizations are responsible for scheduling work efforts, turn T.O. procedures into organized and actionable work packages, identify skill requirements and load work cards. It is imperative they do not introduce factors which jeopardize the integrity or quality of conducting inspections and producing inspection results. They are often central in assisting with communicating with engineering.

<u>BEST PRACTICE</u> ***It is imperative the ALC Chief Inspector (ALC NDI Program Manager) familiarize themselves with the roles and responsibilities of planning and scheduling organizations and to familiarize these organizations to the critical role NDI plays in the overall life cycle management and safety of a system.***

10.1.4 Quality Assurance Organizations

Quality Assurance (QA) inspections provide meaningful metrics on technicians throughout the maintenance complex. QA assessments measure compliance to technical requirements as well as technician performance. QA inspectors generally perform assessments by conducting over-the-shoulder observation of production tasks or by post completion inspection of the task. Roles and responsibilities of Quality Organizations are governed by AFI 21-101, MAJCOM supplements and local OI's

<u>BEST PRACTICE</u>

- ***QA findings and trends should be briefed at least quarterly to maintenance group personnel, commanders and wing commanders. The results could be forwarded to MAJCOM headquarters. The health of maintenance programs could be measured by reviewing QA results and trends. QA trending is a key metric for measuring the effectiveness of NDI processes and process changes.***
- ***QA inspectors must be highly qualified technicians and understand the procedure they are evaluating. This is especially true of inspectors evaluating NDI procedures.***
- ***QA inspectors of a NDI task or organization will themselves have received the appropriate training to evaluate the task or inspector depending on the type of QA inspection being performed.***

10.1.5 AF NDI Program Office

Roles and responsibilities of the Air Force NDI Program Office are currently governed by AFI 21-105. The USAF NDI Benchmarking study identified a number of commercial and DoD Best Practices that should be considered:

BEST PRACTICES

- ***The AFNDIO should be physically located at an ALC to better keep the technical staff connected with issues of the depots and field. The AFNDIO is aligned functionally in AFRL/RX, this facilitates awareness of the NDI R&D program in AFRL/RX along with providing advocacy for the AFNDIO to HQ AF & HQ AFMC.***
- ***The AFNDIO Chief should report directly to the AF Chief Inspector (if established see section 10.2.1) on technical, personnel and logistics NDI issues affecting the AF and AFMC.***

10.2 NDI Managerial Functions

10.2.1 Chief Inspector

The commercial aviation industry (Delta Airlines) implements an NDI organizational structure that places full responsibility and authority for all aspects of the carrier-specific inspection program on the Chief Inspector. There is currently no equivalent within the separate branches of the DoD. Based on the commercial aviation experience the following Best Practices are proposed for potential future implementation by the USAF:

BEST PRACTICES

- ***Establish an HQ AFMC level Chief inspector (currently does not exist) and a separate Depot or Air Logistics Center Chief Inspector at each center.***
- ***The HQ AFMC Chief inspector would hold a similar role, responsibility and authority to that of the AF Aircraft Structural Integrity Program Technical Advisor, a senior leader reporting to the AFMC Director of Engineering.***
- ***The Air Force Chief Inspector would be of national reputation and expertise in the area of Nondestructive Inspection or Nondestructive Testing as referred to in some circles. This individual may or may not possess a Doctorate in Engineering or Physical science. This would not be a prerequisite for holding this position, their experience as an expert in the field of Nondestructive Testing is demonstrated by activities they have accomplished throughout their career. It is envisioned that the AF Chief Inspector would routinely have a NDI Chief Inspector forum supported by the ALC NDI Program Managers (ALC NDI Chief Inspectors), Product centers, and AFRL where issues affecting the command would be addressed to command senior leadership.***

10.2.2 ALC Chief Inspector (ALC NDI Program Manager)

The ALC NDI Program Manager positions currently located at each USAF depots are the basic functional equivalent of an ALC Chief Inspector. Unfortunately the program managers do not currently possess the authority and oversight required by the commercial counterparts: The following Best Practices define the proposed roles and responsibilities of an ALC Chief Inspector:

BEST PRACTICES

- ***ALC Chief Inspectors must be designated by the ALC commander in writing with roles, responsibilities and authority governed by AFI 21-105, AFMCI's and local OIs.***
- ***ALC Chief Inspectors should report to the to the ASC, ASW and MXW Engineering at their respective ALC as well as to the AF Chief Inspector. This would ensure they were able to report the status of the ALC NDI program to senior leadership unabated.***
- ***The ALC Chief Inspector in addition to their AFI 21-105 roles and responsibilities should have responsibilities similar to those of a Chief Engineer for other organizations located at that ALC, that is, they should not be encumbered with other duties not associated with the focus of the NDI program.***
- ***ALC Chief Inspectors should possess expertise in the area of Nondestructive Inspection or Nondestructive Testing and be reputable AF wide as a competent NDI practitioner. Prerequisites should include experience as an expert in the field of Nondestructive Testing, demonstrated by NDI Level III certifications in all the methods used at that depot.***

10.2.3 Depot Production Supervisors

Depot Production Supervisor roles and responsibilities are currently governed by AFI 21-101, AFMCI's and local OI's. The USAF NDI Benchmarking study identified a number of commercial and DoD Best Practices that should be considered:

BEST PRACTICES

- ***First line supervisors must demonstrate sufficient knowledge and experience in NDI to appropriately manage the workload and inspectors. They must also be knowledgeable and sufficiently experienced to effectively address training, qualification, certification and inspection processes and requirements.***
- ***Mandate previous inspector experience for first line supervisors.***

10.2.4 Field Shop Chiefs

Field Shop Chief roles and responsibilities are governed by AFI 21-101, MAJCOM supplements and local OI's. The USAF NDI Benchmarking study identified a number of commercial and DoD Best Practices that should be considered:

BEST PRACTICES

- ***Mandate previous inspector experience for field shop chiefs.***
- ***Field shop chiefs must possess sufficient knowledge and experience in NDI to appropriately manage the workload and inspectors. They must also be knowledgeable and sufficiently experienced to effectively address training, qualification, certification and inspection processes and requirements.***

10.2.5 Wage Leader Coverage

The roles and responsibilities of the wage leaders, wage training leaders vary greatly as the position description cover a vast array of duties. They function primarily as a work leader (pseudo-supervisor), a training leader, and unfortunately are often used as inspectors. It is recommended that the primary role of the wage leader is training the junior inspectors in the shop. Although it has been recommended in this Guide that experienced, designated OJT providers provide the bulk of the OJT, using wage training leaders as trainers helps ensure consistent training throughout the shop.

BEST PRACTICES ***Require Wage Leader coverage for each shift that performs NDI.***

10.3 Communication

Perhaps no other component of the successful NDI shop is as important or vital as communication, to and from all levels, inspector to inspector, inspector to management, inspector to engineering, engineering to engineering, etc.

It is recommended that "open door" policies be implemented at all levels. A culture must be established that questions can be asked without fear or intimidation. The free flow of information and ideas must be created.

One of the problems identified by the Eagle Look was feedback on the inspections. The inspector finds a crack or other defect, then is usually on to the next inspection and never finds out if the crack they found was repaired, replaced or determined to be serviceable until the next inspection. This type of information is seen as crucial to the development of the inspector's sense of worth and to reemphasize the importance of their jobs and the inspections they perform.

BEST PRACTICE **Implement *monthly (minimum) "feedback" sessions between first line supervisors, inspectors and Level III experts to discuss interesting "finds", technical data and upcoming technologies.***

Most military shops have a monthly stand-down day, maintenance down day, or goal day, where they receive briefings and updates, then grill hamburgers or some type of group activity. It is recommended that the civilian shops set aside, as a minimum, one half-day a month, or an extended lunch, to provide feedback to the inspectors and to provide them a forum and audience for discussion.

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12.0 List of Acronyms

AF – Air Force
AFI – Air Force Instruction
AFMCI – Air Force Material Command Instruction
ALC – Air Logistics Center
ASIP – Aircraft Structural Integrity Program
ENSIP – Engine Structural Integrity Program
FSMP – Force Structural Maintenance Plan
HQ AFMC – Head Quarters Air Force Material Command
NDI – Nondestructive Inspection
OEM – Original Equipment Manufacturer
PD – Position Description
POD – Probability of Detection
POF – Probability of Failure
POI – Probability of Inspection
POM – Probability of Miss
QA – Quality Assurance
QAS – Quality Assurance Specialist
SOF – Safety of Flight
TO – Technical Order

Appendix A
Phase I - Procedure Validation Checklist, Penetrant

PHASE I: Validation Checklist
(Insert Procedure ID Here)

1. Inspection Description:
a. Inspection area (attach pictures, figures, sketch, etc.)
b. Materials:
c. Purpose:
d. Detection Capability Need (a_{NDI}):
NOTE: Detection Capability Need must be defined by the responsible SPO engineer prior to formal initiation of the Procedure Qualification Process.

2. Inspection Criticality:
a. Flight Safety Critical Structure Yes ____No ____
i. ASIP-driven Requirement Yes ____No ____
ii. Criticality Identified in NDI Manual Yes ____ No ____
b. Routine Maintenance Yes ____ No ____
c. Engine component Yes ____ No ____
d. Other (identify)

3. Personnel Qualification Recommendation:
a. Civilian (NAS410) : _____ Level II; _____ Level I
b. Military: _____2A772; _____2A752; _____2A732
c. Task specific training requirements identified Yes ____ No ____

4. Equipment Requirements:
a. Type, Method, Sensitivity Level:
b. UV-A Filtering Safety Glasses
c. Penetrant Materials:
d. Magnifiers:
e. Application and Removal Equipment:
f. Other

5. Preparation and Access Requirements (including TO references):
a. Surface preparation
b. Aircraft or component preparation
c. Other

6. Calibration Requirements (include Calibration Standard design):

7. Inspection Procedure Details: Draft Procedure Available Yes _____ No _____
a. Precleaning Method and Surface Preparation:
b. Drying Time and Temperature:
c. Inspection Area Definition Plus 1 Inch Perimeter:
d. Penetrant Application:

i. Application Method:
ii. Minimum, Maximum Dwell Times:
e. Penetrant Removal:
i. Method A Maximum Rinse Times and Temperatures:
ii. Method B/D Maximum Emulsifier/Remover Dwell and Rinse Times:
iii. Method C Solvent and Wipe Procedures:
f. Post Penetrant Removal Drying Parameters:
i. Drying Time
ii. Drying Temperatures
g. Developer:
i. Type:
ii. Minimum/Maximum Dwell Times:
h. Lighting:
i. Type:
ii. Minimum UV-A Intensity:
iii. Maximum White Light Intensity:
iv. Distance/Location:
v. Light Meter Calibration:
i. Inspection Results/Evaluation/Documentation:
j. Backup Inspection Requirements:
k. Post Inspection Calibration Verification:
l. Post Inspection Securing Requirements:

8. Summary of Validation Activities
a. Describe testing and experimental approach
b. Test Specimen Description
i. Manufactured / Actual parts
ii. Defect sizes and distribution
iii. Artificial or Natural Defects
c. Problems, concerns and limitations encountered
d. Results

9. Procedure Capability Assessment Reference the Recommended Processes and Best Practices for Nondestructive Inspection of Safety-of-Flight Structures, Chapter 6 and EN-SB-08=012 for guidance on determining detection capability inspectability factors and adjustment factors.
a. Predicted Detection Capability: ________
b. Basis of predicted capability (include reference data if applicable)
i. Meets EN-SB-08-012 Baseline Assumptions: yes / no
ii. Adjusted per EN-SB-08-012 and Best Practice (details below)
(a) Inspectability Factor (1,2,3,4): ____ (List factors affecting rating)
(b) Adjustment Factor Used: _____
(c) Show adjustment calculations
iii. Other: define/explain
c. Meets engineering defined NDI capability need: yes/no (explain)

Phase I Validation Endorsements

The following endorsements attest that the Phase I Validation Report for (Insert Procedure ID here) has been reviewed and the results support continuation of the procedure qualification process to Phase 2 Verification.

Responsible Level III

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Responsible SPO Engineer

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

ALC NDI Program Manager

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Appendix B
Phase I - Procedure Validation Checklist, Magnetic Particle (Yoke or Stationary Unit)

PHASE I: Validation Checklist
(Insert Procedure ID Here)

1. Inspection Description:
a. Inspection area (attach pictures, figures, sketch, etc.)
b. Materials:
c. Purpose:
d. Detection Capability Need (a_{NDI}):
NOTE: Detection Capability Need must be defined by the responsible SPO engineer prior to formal initiation of the Procedure Qualification Process.

2. Inspection Criticality:
a. Flight Safety Critical Structure Yes ____No ____
i. ASIP-driven Requirement Yes ____No ____
ii. Criticality Identified in NDI Manual Yes ____ No ____
b. Routine Maintenance Yes ____ No ____
c. Engine component Yes ____ No ____
d. Other (identify)

3. Personnel Qualification Recommendation:
a. Civilian (NAS410) : _____ Level II; _____ Level I
b. Military: _____2A772; _____2A752; _____2A732
c. Task specific training requirements identified Yes ____ No ____

4. Equipment Requirements:
a. Type, Method
b. UV-A Filtering Safety Glasses
c. Magnetic Particle Materials:
d. Magnifiers
e. Stationary Magnetic Particle Unit or Portable Yoke
f. Black light
g. Field indicator / gauss meter
h. QQI shim
i. Application and Removal Equipment:
j. Central Bar conductor
k. Other:

5. Preparation and Access Requirements (including TO references):
a. Surface preparation
b. Aircraft or component preparation
c. Other

6. Calibration Requirements(include Calibration standard design):

7. Inspection Procedure Details: Draft Procedure Available Yes _____ No _____
a. Access and Surface Preparation:
b. Inspection Area Description and coverage details:
c. Magnetization Method:
i. Current Type:
ii. Current Level:
iii. Current Direction (Include Sketch):
iv. Number and Length of Shots (in seconds):
v. Extent of Magnetization (inspection area) per shot (include sketch):
vi. Position of part in coil
viii. CBC size
d. Magnetic Particle Application:
i. Application Method:
ii. Continuous/Residual
e. Lighting Requirement:
i. Type:
ii. Minimum UV-A Intensity:
iii. Maximum White Light Intensity
iv. Distance/Location
v. Light Meter Calibration:
f. Demagnetization Method:
g. Inspection Results/Evaluation/Documentation:
h. Backup Inspection Requirements:
i. Post Inspection Calibration Verification:
j. Post Inspection Securing Requirements:

8. Summary of Validation Activities
a. Describe testing and experimental approach
b. Test Specimen Description
i. Manufactured / Actual parts
ii. Defect sizes and distribution
iii. Artificial or Natural Defects
c. Problems, concerns and limitations encountered
d. Results

9. Procedure Capability Assessment Reference the Recommended Processes and Best Practices for Nondestructive Inspection of Safety-of-Flight Structures, Chapter 6 and EN-SB-08=012 for guidance on determining detection capability inspectability factors and adjustment factors.
a. Predicted Detection Capability: ________
b. Basis of predicted capability (include reference data if applicable)
i. Meets EN-SB-08-012 Baseline Assumptions: yes / no

ii. Adjusted per EN-SB-08-012 and Best Practice (details below)
(a) Inspectability Factor (1,2,3,4): ____ (List factors affecting rating)
(b) Adjustment Factor Used: _____
(c) Show adjustment calculations
iii. Other: define/explain
c. Meets engineering defined NDI capability need: yes/no (explain)

Phase I Validation Endorsements

The following endorsements attest that the Phase I Validation Report for (Insert Procedure ID here) has been reviewed and the results support continuation of the procedure qualification process to Phase 2 Verification.

Responsible Level III

Name: ____________________________ Org: _________

Signature: _________________________ Date: ________

Responsible SPO Engineer

Name: ____________________________ Org: _________

Signature: _________________________ Date: ________

ALC NDI Program Manager

Name: ____________________________ Org: _________

Signature: _________________________ Date: ________

Appendix C
Phase I - Procedure Qualification Checklist, Eddy Current

PHASE I: Validation Checklist
(Insert Procedure ID Here)

1. Inspection Description:
a. Inspection area (attach pictures, figures, sketch, etc.)
b. Materials:
c. Purpose:
d. Detection Capability Need (a_{NDI}):
NOTE: Detection Capability Need must be defined by the responsible SPO engineer prior to formal initiation of the Procedure Qualification Process.

2. Inspection Criticality:
a. Flight Safety Critical Structure Yes ____No ____
i. ASIP-driven Requirement Yes ____No ____
ii. Criticality Identified in NDI Manual Yes ____ No ____
b. Routine Maintenance Yes ____ No ____
c. Engine component Yes ____ No ____
d. Other (identify)

3. Personnel Qualification Recommendation:
a. Civilian (NAS410) : _____ Level II; _____ Level I
b. Military: _____2A772; _____2A752; _____2A732
c. Task specific training requirements identified Yes ____ No ____

4. Equipment Requirements:
a. Inspection instrument
i. USAF Standard unit:___ Nortec 2000D series
ii. Other unit: ________________________
b. Probe
i. Type: ___Surface ____Bolthole ____ Other
ii. Description: Shielding, frequency, size, etc.
iii. Brand __________ P/N __________
c. Calibration Standard
i. AF general purpose standard
ii. Actual aircraft component
iii. Local Manufacture, ____ Drawings provided
iv. Master Calibration Required Yes ____ No ____
v. Care / Maintenance / Corrosion Control
d. Cables
i. Brand __________ P/N __________
ii. Description: Length ____, Connector type ____
e. Scanner
f. Other

5. Preparation and Access Requirements (including TO references):
a. Surface preparation
b. Aircraft or component preparation
c. Other

6. Calibration Requirements (include Calibration standard design):
a. Calibration Performance intervals
i. Immediately prior to component inspection
ii. At the completion of a series of component inspections
iii. At specified time intervals
iv. Following any interruption in system or personnel continuity
v. At any instance of suspected system irregularity
b. Initial Equipment Setup
i. Generic equipment set-up per T.O. 33B-1-2 _____
ii. Tabulated Instrument Specific settings provided_____
iii. Tabulated Generic settings provided _____
c. Figures provided detailing initial setup screen presentation _____
d. Figures provided detailing all screen displays expected during calibration
e. Sensitivity Verified by
i. Amplitude Response ____
ii. Response tolerance ____
iii. Repeatability ____
f. Recurrent Calibration Verification Required Yes ____ No ____
i. Intervals specified
ii. Procedure specified
iii. Re-inspection guidance provided for verification failure

7. Inspection Procedure Details: Draft Procedure Available Yes _____ No _____
a. Access and Surface Preparation:
b. Inspection Area Description and coverage details:
c. Scan Coverage detailed in figures
d. Scan direction details
e. Scan increment / overlap details
f. Scan Speed Limitations
g. High pass and low pass filter required
h. Reference marking on part for coverage area
i. Scanning aids / templates required
j. Inspection Results/Evaluation/Documentation:
k. Backup Inspection Requirements:
l. Post Inspection Calibration Verification:
m. Post Inspection Securing Requirements:

8. Summary of Validation Activities
a. Describe testing and experimental approach
b. Test Specimen Description

i. Manufactured / Actual parts
ii. Defect sizes and distribution
iii. Artificial or Natural Defects
c. Problems, concerns and limitations encountered
d. Results

9. Procedure Capability Assessment Reference the Recommended Processes and Best Practices for Nondestructive Inspection of Safety-of-Flight Structures, Chapter 6 and EN-SB-08=012 for guidance on determining detection capability inspectability factors and adjustment factors.
a. Predicted Detection Capability: ________
b. Basis of predicted capability (include reference data if applicable)
i. Meets EN-SB-08-012 Baseline Assumptions: yes / no
ii. Adjusted per EN-SB-08-012 and Best Practice (details below)
(a) Inspectability Factor (1,2,3,4): ____ (List factors affecting rating)
(b) Adjustment Factor Used: _____
(c) Show adjustment calculations
iii. Other: define/explain
c. Meets engineering defined NDI capability need: yes/no (explain)

Phase 1 Validation Endorsements

The following endorsements attest that the Phase I Validation Report for <u>(Insert Procedure ID here) </u>has been reviewed and the results support continuation of the procedure qualification process to Phase 2 Verification.

Responsible Level III

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Responsible SPO Engineer

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

ALC NDI Program Manager

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Appendix D
Phase I - NDI Procedure Qualification Checklist, Ultrasonics

PHASE I: Validation Checklist
(Insert Procedure ID Here)

1. Inspection Description:
a. Inspection area (attach pictures, figures, sketch, etc.)
b. Materials:
c. Purpose:
d. Detection Capability Need (a_{NDI}):
NOTE: Detection Capability Need must be defined by the responsible SPO engineer prior to formal initiation of the Procedure Qualification Process.

2. Inspection Criticality:
a. Flight Safety Critical Structure Yes ____No ____
i. ASIP-driven Requirement Yes ____No ____
ii. Criticality Identified in NDI Manual Yes ____ No ____
b. Routine Maintenance Yes ____ No ____
c. Engine component Yes ____ No ____
d. Other (identify)

3. Personnel Qualification Recommendation:
a. Civilian (NAS410) : _____ Level II; _____ Level I
b. Military: _____2A772; _____2A752; _____2A732
c. Task specific training requirements identified Yes ____ No ____

4. Equipment Requirements:
a. Inspection instrument
i. USAF Standard unit:___ Sonic 1200M ___USN-52
ii. Other unit: ________________________
b. Transducer
i. Type: ___L Wave ____Shear Wave ____ Surface Wave
ii. Mode: ____TT ____PE ____PC ____Immersion ____Other
iii. Brand __________ P/N __________
iv. Description:
1. Size ____ Angle ___ Frequency ____ Connector type ____
v. Wedge Description:
1. Brand__________ P/N __________
2. Modifications _________________
vi. Reference marking required on transducer or wedge
vii. Transducer Acceptance Testing Required Yes ____ No ____
c. Calibration Standard
i. Brand __________ P/N __________
ii. Actual aircraft component
iii. Reference Block: ____FBH ____ SDH ____IIW ____Miniature
iv. Local Manufacture, ____ Drawings provided

v. Master Calibration Required Yes ____ No ____
vi. Care / Maintenance / Corrosion Control
d. Probe/Standard Matching Required Yes ____ No ____
e. Cables
i. Brand ___________ P/N ___________
ii. Description: Length ____, Connector type ____
f. Other

5. Preparation and Access Requirements (including TO references):
a. Surface preparation
b. Aircraft or component preparation
c. Other

6. Calibration Requirements (include Calibration standard design):
a. Calibration Performance intervals
i. Immediately prior to component inspection
ii. At the completion of a series of component inspections
iii. At specified time intervals
iv. Following any interruption in system or personnel continuity
v. At any instance of suspected system irregularity
b. Transducer verifications Required Yes ____ No ____
c. Initial Equipment Setup
i. Generic equipment set-up per T.O. 33B-1-2 _____
ii. Tabulated Instrument Specific settings provided_____
iii. Tabulated Generic settings provided _____
d. Figures provided detailing initial setup screen presentation _____
e. Figures provided detailing all screen displays expected during calibration
f. Sensitivity Verified by:
i. Amplitude Response ____
ii. Distance response
iii. Response tolerance ____
iv. Repeatability ____
g. DAC or TCG Required Yes ____ No ____
h. Attenuation Correction by Transfer Required Yes ____ No ____
i. Recurrent Calibration Verification Required Yes ____ No ____
i. Intervals specified
ii. Procedure specified
iii. Re-inspection guidance provided for verification failure

7. Inspection Procedure Details: Draft Procedure Available Yes _____ No _____
a. Access and Surface Preparation:
b. Inspection Area Description and coverage details:
c. Gain Level adjustment Required Yes ____ No ____
d. Scan Coverage detailed in figures
e. Probe manipulation details

f. Scan increment / overlap details
g. Scan Speed Limitations ____
h. Reference marks on probe for positioning relative to part geometry _____
i. Reference marking on part for coverage area ____
j. Cautions regarding couplant use (adequate / excess)
k. Cautions for maintaining reference signals on display
l. Known reflectors indicated and described
m. Scanning aids / templates required
n. Inspection Results/Evaluation/Documentation:
o. Backup Inspection Requirements:
p. Post Inspection Calibration Verification:
q. Post Inspection Securing Requirements:

8. Summary of Validation Activities
a. Describe testing and experimental approach
b. Test Specimen Description
i. Manufactured / Actual parts
ii. Defect sizes and distribution
iii. Artificial or Natural Defects
c. Problems, concerns and limitations encountered
d. Results

9. Procedure Capability Assessment Reference the Recommended Processes and Best Practices for Nondestructive Inspection of Safety-of-Flight Structures, Chapter 6 and EN-SB-08=012 for guidance on determining detection capability inspectability factors and adjustment factors.
a. Predicted Detection Capability: ________
b. Basis of predicted capability (include reference data if applicable)
i. Meets EN-SB-08-012 Baseline Assumptions: yes / no
ii. Adjusted per EN-SB-08-012 and Best Practice (details below)
(a) Inspectability Factor (1,2,3,4): ____ (List factors affecting rating)
(b) Adjustment Factor Used: _____
(c) Show adjustment calculations
iii. Other: define/explain
c. Meets engineering defined NDI capability need: yes/no (explain)

Phase I Validation Endorsements

The following endorsements attest that the Phase I Validation Report for (Insert Procedure ID here) has been reviewed and the results support continuation of the procedure qualification process to Phase 2 Verification.

Responsible Level III

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Responsible SPO Engineer

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

ALC NDI Program Manager

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Appendix E
Phase I - NDI Procedure Qualification Checklist, Radiography

PHASE I: Validation Checklist
(Insert Procedure ID Here)

1. Inspection Description:
a. Inspection area (attach pictures, figures, sketch, etc.)
b. Materials:
c. Purpose:
d. Detection Capability Need (a_{NDI}):
NOTE: Detection Capability Need must be defined by the responsible SPO engineer prior to formal initiation of the Procedure Qualification Process.

2. Inspection Criticality:
a. Flight Safety Critical Structure Yes ____No ____
i. ASIP-driven Requirement Yes ____No ____
ii. Criticality Identified in NDI Manual Yes ____ No ____
b. Routine Maintenance Yes ____ No ____
c. Engine component Yes ____ No ____
d. Other (identify)

3. Personnel Qualification Recommendation:
a. Civilian (NAS410) : _____ Level II; _____ Level I
b. Military: _____2A772; _____2A752; _____2A732
c. Task specific training requirements identified Yes ____ No ____

4. Equipment Requirements:
a. Film Type:
b. PPE, Dosimeter:
c. Intensifying Screens:
d. IQI's:
e. Tubehead:
f. Other

5. Preparation and Access Requirements (including TO references):
a. Surface preparation
b. Aircraft or component preparation
c. Other

6. Calibration Requirements (include Calibration standard design):

7. Inspection Procedure Details: Draft Procedure Available Yes _____ No _____
a. Access and Surface Preparation:
b. Inspection Area Description and coverage details:
c. Precleaning Method and Surface Preparation:
d. Inspection Area Definitions (include sketch):

e. Component Preparation:
f. Film/Tubehead/IQI Placement Details (include sketch):
g. Exposure Settings:
h. Film Interpretation and Evaluation Guidance:
i. Inspection Results/Evaluation/Documentation:
j. Backup Inspection Requirements:
k. Post Inspection Calibration Verification:
l. Post Inspection Securing Requirements:

8. Summary of Validation Activities
a. Describe testing and experimental approach
b. Test Specimen Description
i. Manufactured / Actual parts
ii. Defect sizes and distribution
iii. Artificial or Natural Defects
c. Problems, concerns and limitations encountered
d. Results

9. Procedure Capability Assessment Reference the Recommended Processes and Best Practices for Nondestructive Inspection of Safety-of-Flight Structures, Chapter 6 and EN-SB-08=012 for guidance on determining detection capability inspectability factors and adjustment factors.
a. Predicted Detection Capability: ________
b. Basis of predicted capability (include reference data if applicable)
i. Meets EN-SB-08-012 Baseline Assumptions: yes / no
ii. Adjusted per EN-SB-08-012 and Best Practice (details below)
(a) Inspectability Factor (1,2,3,4): ____ (List factors affecting rating)
(b) Adjustment Factor Used: _____
(c) Show adjustment calculations
iii. Other: define/explain
c. Meets engineering defined NDI capability need: yes/no (explain)

Phase I Validation Endorsements

The following endorsements attest that the Phase I Validation Report for (Insert Procedure ID here) has been reviewed and the results support continuation of the procedure qualification process to Phase 2 Verification.

Responsible Level III

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Responsible SPO Engineer

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

ALC NDI Program Manager

Name: ______________________________ Org: __________

Signature: ___________________________ Date: _________

Appendix F
Phase II - NDI Procedure Verification Checklist, All Methods

PHASE II: Verification Checklist
All Methods
(Insert Procedure ID Here)

1. Responsible Level III:

2. Responsible SPO Engineer:

3. Type of Verification:
a. Performance ______
b. Simulation ______
c. Desk Top Analysis ______
Justification for use of Simulation or Desk Top Analysis:
ALC NDI Program Manager Signature:
Responsible SPO Engineer Signature:

4. Flight Safety Critical Structure: Yes / No
a. Crack miss and human factor mitigation processes instituted: Yes / No (provide details below)
i. Task specific training
ii. Two-man team
iii. Redundant Inspection
iv. Engineering oversight
v. Level III oversight
vi. New technology or equipment
vii. Defect mapping / Defect recording criteria
viii. Coating removal or other part preparation emphasis
ix. Scanning aides / mirrors
x. Recommended inspector break frequency
xi. Inspector Fatigue reduction recommendations
xii. Lighting or other facility requirements
xiii. Access requirements
xiv. Other ____________

5. Summary of Verification Activities
a. Logistical Details (date, location, A/C serial no., participants, etc.)
b. Procedure has been reviewed for thoroughness and ease of use
c. Lowest Skill-Level Recommended for Use: Civilian/Military
d. Equipment Performance and Availability
e. Part preparation techniques

f. Description of test specimens or calibration standards
g. Recommendations for specialized training or certification
h. Estimation of inspection process man-hours
i. Estimation of preparation man-hours
j. Inspection Results
k. Method or part specific issues
l. Configuration difference or change driven issues

6. Capability Assessment
a. Phase I Predicted Detection Capability confirmed: Yes / No (explain)
b. False-call estimate:

7. Procedure Implementation Considerations:
a. Routine Scheduled Inspection:
b. TCTO:
c. Equipment Availability:
i. Standard inventory items:
ii. Specialized equipment necessary
1. Kitted
2. Non-Kitted
3. SPO/Command Funded
4. Local Funding
d. Equipment Durability
e. Alternate equipment allowed Yes ____ No ____
f. Alternate Equipment Approval process identified Yes ____ No ____
g. Task Specific Training Details
i. Individual _______
ii. Train the Trainer _________
iii. Web Based _________
iv. Recurring ________
v. Recommended Source ________
vi. Location __________
vii. Funding required / available Yes____ No_____

Phase II Verification Endorsements and Procedure Approvals
(Insert Procedure ID here)

Verification Inspector(s)	
Comments:	
Name:	Org.:
Certification: ____ Level II; _____ Level I; ____ Other	
Signature:	Date:

Level III Verification Witness	
Comments:	
Name:	Org.:
Signature:	Date:

Structural Engineering Verification Witness	
Comments:	
Name:	Org.:
Signature:	Date:

Responsible Level III	
Procedure Approved / Disapproved for release (circle as appropriate)	
Comments:	
Name:	Org.:
Signature:	Date:

Responsible SPO Engineer	
Procedure Approved / Disapproved for release (circle as appropriate)	
Comments:	
Name:	Org.:
Signature:	Date: